INVESTIGATIONS

ON

IRON AND STEEL RAILS,

MADE IN EUROPE IN THE YEAR 1873,

BY

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DURING the year 1873, my attention was called to the frequent accidents, resulting from the breaking of rails, on the different railroads in this country, and I was requested to investigate the subject. The plan of investigation I proposed was to ascertain, in as many cases as possible, the exact history of broken rails, both in this country and in Europe; to collect information in Europe relating to the tests which rails used there were required to undergo, and to experiment upon the pieces of rails broken on the road, with a view to ascertain whether their fracture was due to their chemical constitution, bad manufacture, to a reduction in strength owing to temperature, or to physical changes in the constitution of the rail.

The investigation was commenced by the collection of statistics, and for this purpose I spent several months in Europe, collecting information on the subject of broken rails, as well as the life of iron and steel rails generally, and inquiring into the systems of purchasing and of testing them employed by the railroads there, intending, on my return, to make a series of analyses of rails broken, both in this country and in Europe; to ascertain, if possible, how far great cold had an influence on the fracture; to examine whether the rail broken, either on the road or afterwards, underwent, at or about the fracture, any physical change, and to make a series of experiments on the strength of rails manufactured in the United States or sold in the American market.

Unfortunately, the panic of 1873 came on, just before my return from Europe, and prevented the carrying out of the larger part of the plan proposed; as, however, I had collected in the meantime, a large number of statistics of different kinds from all parts of Europe, and had made a number of interesting experiments and investigations, I have thought it would be worth while to communicate some

of the results to the Institute. These investigation are, unfortunately, not complete in any sense, since they were suddenly brought to a close shortly after they were commenced in Europe, and before anything had been done in this country, so that what I have to communicate will be mostly results obtained in France and Belgium, from experiments made on broken rails, and statistics collected with regard to them, and information relating to the purchase of rails and their wear upon some of the principal roads. Some of these results have not, as yet, to my knowledge, been published, and most of them are interesting, as they bring together a series of facts collected over a number of years, on some of the longest and most important lines in Europe.

The purchase of railway supplies and material in Europe differs entirely from that in vogue in this country. Rails are very rarely purchased in the open market, but are almost invariably made by contract with the manufacturer, after patterns furnished by the railroad companies, and expressly for them. For the purchase of supplies a large number of forms of contract, which are either autographed or printed, are provided. Each railway has from twenty to twenty-five of these documents relating to the road-bed and its supplies alone. They enter into every detail with regard to the ties, chairs, plates, wedges, spikes, bolts, nuts, screws, fish-plates, and every possible material that the railroad company has to buy. These contracts are drawn up by the engineers in charge of each one of the different departments, and are submitted to the engineer-in-chief for approval. They are altered from time to time, as the necessities of the case may require. They bind the contracting parties in such a way as would scarcely be tolerated in this country, but their general result is most careful management on the part not only of the contractors, but of all of the employés of the road. These printed or autographed contracts are furnished, on application, to the manufacturers wishing to bid for the contract for furnishing any of the supplies. All the supplies, of whatever nature, are subjected to the closest inspection, not only when finished, but in all stages of their manufacture, and the contract specifies that during the time of the execution of the contract the engineers of the company shall, both during the day and at night, have free access to the works, and be at liberty to examine every part of the article being manufactured, in every stage, from the crude material up to the time of delivery, in order to verify that the conditions of the contracts are being fulfilled. During this time the engineer in charge is always at liberty

to reject the whole or any part of the material which is not up to the standard. As the strength of the rail is stipulated in the contract, a certain number of experiments are made in the presence of the engineer of the manufacturer furnishing the rails, but under the direction of the engineer of the railroad company, sent to the works for that purpose. None of the verifications, however, have the effect of in any way diminishing the responsibility of the guarantee of the life of the rail for the time fixed in the contract. No manufacturer is allowed to underlet any part of his contract to another manufacturer without the written consent of the company. The acceptance of the works by the company does not guarantee the whole payment until the article contracted for, whether it is a car, a rail, a water-tank, steam-engine, or any other material about the railroad, has worn well and without repairs during a certain specified time.

Most of the rails manufactured are of the ordinary American pattern, though some companies still use the double-headed rail. Iron rails are not so generally used as formerly. On all the principal roads their place is being rapidly replaced by steel. Steel-headed rails are used by some of the companies, but there is no certainty that the weld of the iron to the steel will always be perfectly made. The general experience is that there is a tendency for the two materials to separate. There have been a great many ingenious plans proposed, to make the iron clamp the steel, or the steel clamp the iron, but in view of the experiments made at the Northern Railroad of France, it does not seem worth while to lay any but steel rails, more especially as the old steel rail has a value which no combination of iron and steel could have.

It does not necessarily follow, that what is done in Europe, is better than what is done in this country. On the contrary, European railway companies have a great deal to learn from the practice of this country, as is shown by the repeated reports made by engineers of different countries, sent here for that purpose by their governments; but in the manufacture of rails and the study of their wear and tear, we have something to learn from them. I have taken some pains to compare the contracts for the purchase of rails made by different companies, and give below an abstract of the contracts made for the purchase of both iron and steel rails, including the stipulations of all the roads of France whose contracts I have been able to procure. There is, necessarily, a great deal of sameness in these contracts, and as no one of the roads imposes all of the conditions which I give below, I have given the contracts somewhat

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in detail, at the risk of being tedious, since I do not know that they have heretofore been published in English. They are, certainly, not generally within the reach of our members.

CONTRACTS FOR IRON RAILS.

All of the roads furnish either a drawing or a steel pattern of the form of the rails, and the manufacturer is not allowed to make the rails until the company is assured that the rolls agree perfectly with the shape furnished. The toleration allowed in the transverse section is only ½ mm. more or less. This is done in order to take into consideration the difference which may arise from the wearing of the rolls, and accidental differences in the distance between them. They require a specimen, showing the quality of the iron to be used in the rails, to be sent to the office in Paris. The iron rails used by the Lyons and Orleans Railroad, are several types of the American and of the double-headed rail. For the double-headed rails the length is 5 m. for nine-tenths of the order; the last tenth may be composed altogether or in part of rails 4.96 m. To facilitate the manufacture, one-thirtieth part of the rails may be admitted 3.75 m. For the American rail, on the Lyons road, the length is 6 m. for nine-tenths, and 5.96 m. for the last tenth; one-thirtieth of the order may be in lengths of 5 m. and 3.75 m. The Northern Railroad contracts for rails of the American pattern of 37 kils. The normal lengths of this rail are 6 and 7 m. For a part of the contract which may not exceed one-tenth, and which is fixed by the chief engineer, the rails may be 6.96 m. to 5.96 m. long. One rail in twenty may be delivered of a shorter length than these, and may be either 4 or 5 m. It is always understood by all the roads that the short rails are to be manufactured from the long ones, which have to be cut on account of defects at their extremities. All the roads stipulate that they may order a certain number of rails of exceptional lengths, providing that the greatest length shall not exceed 10 m.

The Lyons road agrees to pay for all rails exceeding 6 m. in length 5 per cent. above the ordinary price. The Northern Railroad agrees to pay only 4 per cent. A toleration of two millimetres, greater or less, is accorded by the Lyons and Orleans Railroad in the length of the rail, provided that on the whole order it shall not exceed one per cent. The toleration fixed by the Northern road is never more than 1½ millimetres.

All rails which have been manufactured in the trials of the rolls, and all others manufactured after the rails have been accepted, but

which are not in accordance with the model furnished, are rejected. The companies are always at liberty to change the shape of the rails, providing always that the special expenses necessary for these changes shall be allowed to the manufacturer.

The weight of the rails is determined by the model, and is ascertained by trial of the first rails delivered. In the reception of the rails, a toleration of 2 per cent. above or below is allowed, providing that the weight of the whole contract does not vary more than one per cent. Within this limit of toleration, the rails are paid for at their actual weight. Above it, the iron is not paid for, and any rails outside of the limits, either weighing too little or too much, may be rejected entirely if the company think best.

The blast-furnaces which produce the cast iron used are required not to use any ore which gives a brittle iron. If the rail is allowed to be made of different qualities of iron, the head *must* be fine-grained, but in general, the manufacture must be so conducted as to produce only fine-grained iron. It must be weldable, as hard and compact as the specimen which is furnished to the manufacturer, and not cold-short; in short, of a quality to resist the action of the wheels of the train without breaking, crushing, or becoming unwelded. The Northern Railroad classifies the iron to be used into three distinct classes, namely: first, granular iron; second, iron composed partly of grains and partly of fibres, and third, fibrous iron. In the packages for making refined iron, only first-class granular iron must be used. The Lyons Railroad prescribes that the foot of the American rail shall be made of fibrous iron. It requires that the piles shall be composed of two-third puddled iron and one-third merchant iron; that the width of the package shall be 20 centimetres at least, and its height 22 centimetres, and that its weight shall be 40 kilogrammes heavier, at the least, than that of the rail. All the bars used in making up the different layers must be of rectangular section. Each layer of puddled iron may be made up in width of two or three pieces at the most. The layers of refined iron which form the upper part of the package must all be of a single piece, and must represent one-fifth of the total weight of the package, in order to have in the section of the finished rail, on the surface exposed to the wheels, a thickness of at least one centimetre. The layers which are next to them should be entirely composed of the best puddled iron. All the pieces composing the package must be of a single length and straight. For the puddled iron, however, a few bars are allowed of two pieces, at the most, the smallest piece of which must be at least 30 centimetres

in length. They, however must be adjusted end to end, with care, in such a way as to leave the least possible space in the interior of the package. No joint in the package should be directly above another joint, and for this reason the bars of puddled iron should not be of the same width. Fibrous iron may be used only in the last third of the package. Between it and the two first layers, granular iron only must be used. The Orleans Railroad allows the rail to be made entirely of puddled bar, or with such a proportion of old rails as the manufacturers think best. The packages, of which the covering for the head is made, must be made exclusively of rectangular bars placed together on the flat side, in regular layers, with cross joints, and each bar should be 54 mm. in width at the least. The packages for the head of the rail should be rolled flat, and not on the edges, so that the width of the covering will be parallel to the direction of the layers. The cover must be made of puddled iron of the best quality. It must be of a single piece, and represent one-third of the total weight of the package. The Lyons Railroad requires that the puddled iron used, either in the body of the packages for rails, or in the manufacture of the merchant iron for covers, should be of good quality, carefully worked, and the edges of the bars should be smooth. When they are shorter than the package, they must be placed together carefully, end to end, in such a way as to leave the least possible space between them. In the works where the rails are rolled in a single heat, the packages must be turned in the furnace, end for end, when the heat is three-quarters finished. In the works where there are two heats, it must be turned at the commencement of the second heat. All the companies reserve the right to prescribe in what direction the packages shall be rolled, and all require that the name of the manufacturer must be engraved in the last curve of the rolls, so as to be distinctly seen in each rail. The dimensions, form, and composition of the packages, as well as the drawings of the successive curves in the rolls, must be submitted to the company, without, however, this diminishing in any respect the responsibility of the manufacturer.

All the roads require that the rails shall be as carefully manufactured as possible, and that all those badly welded, laminated, cracked, or broken in any way, must be rejected. They require that they must be perfectly flat, both on the foot and head, and if they are not so, they must be straightened on their four faces with the greatest care, or rejected. This straightening is invariably required to be done, as far as possible, hot, immediately after the rails

leave the rolls. If they, afterwards, when cold, require to be straightened, it must never be done by percussion, but by gradual and slow pressure produced by means of a screw.

All the surfaces of the rails must be clean and uniform. All the roads require that the ends of the rails must be cut off at a sufficient distance to be sure that the rail end is perfectly sound. All projecting iron must be removed either with a file or a graver, and the ends of the rail must be square with its axis. They all require that the final length should be made by cutting one of the ends in a lathe, planing machine, or with a milling tool, in such a way that there shall be no tearing or any other alteration of the surface at the end, and that all excess of matter shall be removed with a file or graver, but on no account with a hammer. Reheating any part of the rail, either to cut off the ends, or for any other reason, is positively forbidden, except in case of temporary accidents to the machine used for cutting them, and then, if absolutely necessary, only during the time that is strictly necessary to repair it. Every kind of repair done to cracks or other inequalities in the rail, whether done cold or hot, is forbidden.

Each extremity of the rail is pierced with two round holes, to receive the bolts of the fish-plates, the dimensions and position of which are fixed by a drawing furnished by the engineer. The Lyons road provides that in some cases one of these holes may be half round. Two cuts of a rectangular form must be made at the extremity of the American rail to receive the wedges which prevent its motion forward, the position and size of which are also given. These holes and cuts may be made by any process which shall suit the engineer of the company, but in any case the edges of the holes and of the cuts must be filed smooth and not left rough. If the positions of the holes and cuts do not conform to the drawing, the rails may be rejected. The rails must be classified in series, according to the manufacture of different days.

The Northern and Orleans Railroad require the rails to undergo the following tests. Each one of the rails selected for trial is placed on supports 1.10 m. apart, and must sustain, in the middle between the two supports, a pressure of 12,000 kgs. for five minutes, without preserving any sensible set after the test. The same rail, in the same position, must support during five minutes, without breaking, a charge of 30,000 kgs. The Orleans Railroad requires 25,000 kgs.

At the Lyons Railroad, the rails are placed on supports 1 m. apart, and should support a pressure of 13,000 kgs. for five minutes, with-

out showing any perceptible set, and then for another five minutes, without breaking, a charge of 27,500 kgs.

After these tests, all the companies require that the rail should be broken by an increase of the weight. The Northern and Orleans Railroad require, that each one of the two pieces of the rail broken should be placed between supports 1.10 m. apart,—the Lyons Railroad makes the distance 1 m.,—and should then support, without breaking, the shock of a weight of 200 kgs.,—the Orleans Railroad requires 300 kgs.,—falling in the middle between the supports from a height of 2 m. for the Orleans Railroad, and for the Lyons and Northern Railroad, from a height varying, according to the temperature,

From	0° C., and below, of	1.30 m.
From	0° C. to +20, of	1.50 "
From	+20° C. and above, of	1.70 "

This variation is made as the rails are not considered as capable of resisting as great a strain in cold weather as in warm. All the roads require that for this test the two supports should rest upon a block of cast iron, weighing at least 10,000 kgs., placed upon masonry at least 2.30 m. in diameter and 1 m. thick. The Orleans Railroad allows the foundation to be of oak or masonry. If one of the rails tested does not resist, the tests are continued upon a greater number. If more than one-tenth of the rails do not resist, all the roads reserve the right to reject the entire series.

Provisional receptions are being made at the works, as the rails are manufactured, for the object of sorting, weighing, and marking them. Up to the time of their being sent to the company, the rails must be preserved in a dry place, and kept from oxidation as far as possible. Those accepted must be marked at their ends, and in case the name of the works, made by a cutting in the last curve of the rolls, should not have come out in rolling, it must be marked cold in such a way that it shall be visible. The rails which have been rejected must either be broken, or marked in such a way that the mark cannot be effaced.

All the roads provide that the tools for making the tests, as also all the labor of accepting and testing the rails, must be made at the expense of the manufacturer. The report of the tests and receptions are made every day. Every rail marked, and comprised within the report of acceptance made at the works, becomes, by the act of reception at the works, the property of the company.

All the roads require the manufacturers to allow the agents or

engineers of the companies to have free entry to the works during the time of manufacture, and to watch it day and night, if they wish to ascertain whether the conditions of the contract are being carried out with respect to quality, resistance, and proper manufacture; but it is understood that all observations or remarks which the agents of the company have to make, should be addressed to the director of the works and not to the workmen.

The manufacturer is made responsible for all delays which may result from the rails delivered not being in accordance with the contract. The Orleans Railroad stipulates that, if there is any delay in the delivery of the rails, an indemnity of one per cent. per month on the price of the rails may be charged to the manufacturer. If after having been notified that this delay is injuring the company, the manufacturer still delays to furnish the rails for a month longer, the company is at liberty to rescind the contract.

The manufacturer takes all the risk and expense of loading, transporting, and discharging the rails up to a point agreed upon by the company for delivery, and he agrees to pile them there in regular piles.

The Northern Railroad requires that the rails must stand a wear of at least two years without any alteration whatever. The Lyons Railroad requires that they shall stand the passage of at least 15,000 trains. The Orleans Railway makes the life of the rail 2, 3 and 5 years, depending upon the traffic over the section of road on which it is placed, and stipulates that this guarantee does not apply, in any way, to provisional lines, nor to switches in the quarries, etc., but only to the main line of the road. The manufacturer agrees to make a stipulated reduction in the price of the rails according to the number which have not resisted during the prescribed time.

The Northern Railway requires that 10 per cent., at least, of the rails furnished are to be placed on the road in positions selected by the company, of which the manufacturer is to be notified. At the end of two years, the number of rails which have undergone any kind of deterioration, such as crushing, unwelding, exfoliation, or breaking, are counted, and allowance must be made for them by the manufacturer. It reserves the right to commence the testing of rails on the road-bed whenever it pleases, but agrees that the indemnity must be settled within two years, at the latest, after the receipt of the rails, whether the trial on the road is finished or not. The responsibility of the manufacturer does not cease until the rails have been definitely accepted by the company.

All the roads provide that the reception of the rails by the company does not diminish the responsibility of the manufacturer to replace rails which break, either in transportation or within the times specified by the contract after they are laid. The Orleans Company requires that broken rails shall be replaced within a month after the manufacturer is notified that they are broken.

All the companies stipulate that no part of the contract can be sublet without the written sanction of the company.

The Lyons and Orleans Railroad agree that 85 per cent. of the value of the rails which have been received at the works shall be paid in the course of a month, after their reception, 10 per cent. within a month which follows the delivery of the rails at the place agreed upon by the company; the last 5 per cent. is paid by the Lyons Company on the final reception, and by the Orleans Company the year after the guarantee of the rails has been fulfilled. A certain sum is fixed by the Orleans Railroad, however, which the last five per cent. shall not exceed, and when this amount retained exceeds the amount stipulated, the second payment is raised to 15 instead of 10 per cent.

CONTRACT FOR STEEL RAILS.

The contract for delivery of steel rails generally requires, that the rail shall be of the American pattern, a steel or iron profile of which is furnished to the manufacturers. It requires that this profile shall be followed exactly, throughout the entire length of the rail, so that there will be no alteration of the section, when the rails are cut to length. All rails which do not fulfil this condition are rejected. A toleration of one per cent., however, at the greatest, is allowed. On the Lyons Railroad the rail weighs 35 kgs. They provide the foot of the rail shall be 100 mm. wide, its height 128 mm., and the stem of the rail 14 mm. thick. If the manufacturer makes a rail 130 mm. wide, whose foot has been damaged in the rolls, they will allow him to plane it down to 100 mm., providing that all the defects are in this way removed. The Northern and Orleans Railroad do not prescribe the dimensions, but furnish the pattern which the manufacturer is required to follow.

The normal length of the rail at the Northern Railroad is 8 m., but one-tenth of the amount of the contract may be delivered in rails cut to the length of 7.96 m. Besides this, another fraction, which varies from one-fifteenth to one-twentieth, may be delivered 7 m., 6 m., 5 m. long respectively, the quantities of each length being fixed

by the company. At the Lyons Railroad the length of the rail is fixed at 6 m. for nine-tenths of the whole order; the other one-tenth may be composed in part of rails 5.96 m. in length. In order to facilitate the manufacture, one-thirtieth part may be accepted in rails of a shorter length than 5.96 m., but it is understood that these rails shall be made entirely of rails intended to be 5.96 m., or 6 m. in length, which were cut off on account of defects in their ends. The number of these short rails is determined by the contract. All the companies stipulate that the short rails shall be made from rails intended to have been longer, but whose ends have been cut on account of defects. All the companies reserve the right to order longer rails, for a certain price fixed upon beforehand.

The rails are generally cut to length hot, as they come from the rolls, by means of saws which cut both ends at a time. The definite length is afterwards given in a lathe, or milling machine, or by any other means which is not likely to injure the end of the rail, and which is acceptable to the company. The Lyons Railroad reserves the right of at any time modifying the shape of the rail, without the manufacturer being able to claim any indemnity, but the company binds itself to accept all the rails made previous to the modification, and conformable to the present contract. The normal weight of a metre of the rail is always established on the first delivery of 100 rails, whose sections are conformable to the model. In the reception at the works, a toleration of 2 per cent. more or less is allowed, provided that on the whole order the variation does not exceed 1 per cent. Over 1 per cent. the increase of weight is not paid for. A rail which is too heavy, may be entirely rejected if the company see fit.

The cast iron and other material, out of which the steel rail is to be made, must be made from ores sufficiently pure to be certain that the rail produced will be tenacious and hard. The cast steel manufactured may be made either in crucibles or in furnaces, or by the Bessemer process. Sometimes the contract specifies that they shall be of Bessemer steel. The operation must be conducted in such a way as to give first-class steel, fine-grained, homogeneous, hard, tenacious, and capable of being tempered throughout, when drawn out into bars of from 15 to 22 mm. square. In all cases the manufacturer is required to furnish samples to which the rails must conform. The manufacture of the rails is not allowed to commence until a type specimen of the steel has been submitted to the engineer of the company. The ingots for the manufacture of the rail are

required to be of, at least, a single piece for each rail. The Northern Railroad, for the rail of 30 kgs., requires the section of the ingot to be at least 22 by 20 cm., if they are square, or if circular, a diameter of 23 cm. The Lyons Railroad requires for the rails of 35 kgs., the rectangular ingots to have their angles rounded, to be at least 25 cm. square, or if they have a circular section, a diameter of at least 28 cm., and stipulates that the weight of the ingot must exceed that of the rail to be manufactured by at least 35 kgs. The Orleans Company does not prescribe the size of the ingots. The section of these ingots may not be modified without the approbation of the engineer. After casting the ingots, the liquid metal must be covered over with a piece of sheet iron, and argillaceous sand must be thrown upon it and pressed down, so as to fill up the interior of the mould at the top. The ingots must be examined with care, and those which show blow-holes or impurities, or other defects, which the rolling will not cause to disappear, are rejected. Simple cavities, as well as thin edges of metal on the sides, whether caused by defects in the ingot moulds or not, must be cut off with the greatest care before the ingots go to the rolls, and over a sufficient space to make it impossible for the sides of the blow-hole or of the edges to turn over. Any ingots showing cracks or breaks, or otherwise defective, are to be rejected. The ingots must be heated only sufficiently for them to undergo the operation of rolling, and the rolling must be so conducted as to get the exact form of the rolls, and every effort must be made to prevent the rail from being bent as it comes out of the rolls. The Orleans Railroad requires, that in case the manufacturer carries on his works in two places, and that the ingots are made at a different place from that in which the rails are made, the ingots must be classified separately, and their place of manufacture indicated by marks, so that the agents of the company may be able, if necessary, to ascertain the history of their manufacture. One ingot out of every twenty castings is broken. If this ingot shows, in the part adjacent to the outside, blow-holes in any number which are more than 30 mm. in depth, the entire casting from which it came may be rejected.

The fracture of the rails must be fine-grained, nearly compact, entirely homogeneous, without brilliant white points resembling the fracture of cast iron. The hardness is regulated by the type specimen which is furnished by the company. Repairing the rails, either cold or hot, is positively forbidden. The surfaces of the rails are required to be smooth and uniform. All the rails which show

cracks, breaks, lamellated surfaces, etc., coming from blow-holes, cracks, or flaws of any kind are rejected. Only such superficial cracks or imperfections are tolerated, as cannot in any way injure the strength of the rails.

All the roads require that the rails shall be straight through their entire length, and that they must, as far as it is possible, be straightened on all the four faces hot, as they come out from the rolls. This must be done on cast-iron plates, or any other suitable bed arranged for the purpose, and the rails must then be placed on a solid structure to cool. The final straightening, made when the rail is cold, must be made by a gradual pressure, without shock, and in performing the operation the foot of the rail must be arranged in such a way that there will be no danger of cracks being produced in it.

The ends cut off from the rails must be examined for texture, and if the quality is not sufficiently good, the rails are to be rejected. The length to be cut off from the ends of the rails, is 70 cm. for the extremity corresponding to the upper part of the ingot, and 30 cm. for that corresponding to the lower part. The hot rails, as they come from the rolls, are to have both ends cut with a saw. The final length is given cold in a lathe, planing or mortising machine. Heating the ends of the rails, in order to cut them, is positively forbidden. Whenever the rails are cut with a saw, as they come out from the rolls, their ends must be carefully dressed. Whatever the method of dressing the ends may be, it must be conducted in such a way as to make no alteration in the form of the end of the rail, and the method must always be approved by the company. The end surfaces of the ends of the rails must always be parallel and at right angles to the axis of the rail. All superfluous metal must be cut off with a graver or file, the use of the hammer for this purpose being positively forbidden.

All the rails must have two square cuts at each end, and must also have at each end two holes for the fish-bolts, which must be bored with a drill in the stem of the rail, in accordance with plans and drawing which are given, and which prescribe not only the size and place of the holes, but also the methods of boring them. These holes must never, for any reason, be punched. The edges of these holes must be perfectly clean, and all superfluous metal must be removed with a file. The Orleans and Lyons Railroad allows a toleration of only ½ millimetre in the distance and size of these holes.

All the rails must have the name of the works, the year and

month of the manufacture, and the kind of steel, whether cast, Bessemer, or Martin, marked on them in relief. All these marks must be engraved in the rolls, except that denoting the nature of the steel, which may be made with a point after the rails are finished.

All the rails are classified as soon as possible after they are made, so that they can be inspected and tested at the works, those made during one, two, three, or four days, or those from the same casting, being piled together. The engineer designated to receive the rails, takes from these piles a number of rails, and the corresponding rail ends, to be tested. The number is variable; it is not more than one per cent. on the Northern Railroad, and not more than one-half per cent. on the Lyons Railroad, while the Orleans Railroad reserves the right to test five per cent. of the rails, and their crop ends. The companies reserve the right of making tests on any other rails not comprised in these piles, provided the piece experimented upon is 0.70 m. in length, and without flaws. The tests are essentially the same in all the companies, but differ somewhat in detail, the differences corresponding, for the most part, to the weight of the rail. All the companies use the same type of testing machine, and a weight of 300 kgs., which is allowed to fall on the rail from different heights. At the Lyons Railroad, where the rail weighs 35 kgs., each one of the rails selected from the piles to be examined, is placed upon its foot between supports, 5 m. apart, and should be able to support, for five minutes, a charge of 2500 kgs., without receiving a permanent set of more than 1 mm. The same rail, placed between supports 1 m. apart, must support for five minutes, in the middle between the supports, a pressure of 20,000 kgs., without receiving a permanent set of more than $\frac{1}{4}$ mm. The same bar, in the same position, must support during five minutes, a charge of 35,000 kgs., which will then be increased until the rail breaks. At the Northern Railroad the tests of pressure are somewhat different. The rails are placed on supports 1.10 m. apart, and must support, in their middle, for five minutes, without receiving any permanent set, a pressure of—

20,000 for a rail weighing	37 kg.
18,500 " " "	35 "
17,000 " " "	30 "

Without having a permanent set of more than 0.25 mm. a pressure of—

35,000 for a rail weighing	37 kg.
33,000 " " "	35 "
30,000 " " "	30 "

The Orleans Railroad requires that the rail, placed on supports 1.10 m. apart, should support a weight of 16,000 kgs. for five minutes, without preserving any set, and without breaking; a weight of 35,000 kgs. also for five minutes. The pressure is then increased until the rail is broken.

At the Northern Railroad each one of the halves of the rail so broken, is then placed between supports 1.10 m. apart, which are fixed upon a block weighing, at least, 10,000 kgs., supported upon a foundation of masonry, which must be 1 m. in thickness, and 3.3 m. square at the base, and must bear, without breaking, a weight of 300 kgs. falling upon the middle of the bar, which, for a rail weighing

37 kgs., must fall from a height of	2.50 m.
35 " " " " "	2.40 "
30 " " " " "	2.25 "

The Lyons Railroad, for the rail weighing 35 kgs., requires a height of 1.70 m.

The following table shows the permanent set which will be admitted for rails of various weights by the Northern Railroad:

Height of fall in metres, ...	1	1.50	2	2.25	2.40	2.50
Permanent set in mm. for rails weighing 37 kgs.,	1	3	6	0	0	10
" " " " " 35 "	1	3.33	7	0	11	0
" " " " " 30 "	1	3.50	8	11	0	0

The Lyons Railroad requires the height of fall, 1.70 m.; permanent set for rails weighing 35 kgs., not over 12 mm. The Orleans Railroad requires the rail to resist a height of 2.10 m.

The elasticity of the bar will be shown by the way in which the weight rebounds when it strikes.

If one of the bars tested breaks below

2.50 m., for a rail weighing	37 kgs.
2.40 " " " "	35 "
2.25 " " " "	30 "

or should preserve at this height, a permanent set of more than 2 mm. beyond that indicated, the Northern Railroad requires the test to be continued on a greater number of rails, and if more than 1-10th of the rails tested do not resist, the entire pile from which they were taken is rejected.

The Orleans Railroad provides that all the five crop ends of the rails selected may be broken by the drop-hammer, in order to examine their texture, and that the rail corresponding to the rail end

which has the worst fracture, shall be selected as the one to undergo the test of shock. If this rail resists, the rest of the series will be accepted, but if, on the contrary, it breaks, a second rail will be tried, and so on. If each one of the five rails breaks then the whole hundred will be thrown out. At the Lyons Railroad, if one rail does not stand the test, all the rails from the same casting may be rejected, unless the manufacturer desires to continue the testing upon two other bars which, if they resist, will cause others to be accepted. At each casting, one ingot heavier than the others is required to be made, in order to get a sound rail of 70 cm. greater length than the others. This 70 cm. is at once cut off from the rail, and must correspond to the upper end of the ingot.

The number of the casting, and the other marks made upon the ingot from which this end for testing was made, are reproduced upon the piece of rail. This piece of the rail is placed on two supports 50 cm. apart, and must support the shock of a weight of 300 kgs. falling on the middle from a height of 1.30 m. The two supports are made of cast iron, with round angles, and rest upon the same kind of a foundation as that upon which the rails are tested. When this end of the rail does not support the test, a rail of the corresponding casting is submitted to the test of shock and flexure, and if it does not resist, the whole casting may be rejected.

A piece of the head of the rail, at least 20 cm. in length, is then broken and heated to cherry-red and plunged into cold water, in order to get a hard temper. The surface of the piece should then be white, perfectly clean, and with difficulty touched with a file. If the steel is of good quality it should, during its immersion, produce considerable noise, with slight explosion, and crack in several places. It must be broken afterwards in the middle, in order to judge of the degree of temper and the transformation of its texture. A piece of the same rail, 3 cm. wide and 2 cm. thick, is then drawn out and submitted to the same test. The result should be the same, but the grain of the fracture should be much finer than that of the specimen of the rail tempered without being drawn down. The test of tempering is made upon one casting out of ten consecutive ones. From a piece of the same rail a graver, a turning tool, a mortising tool, and a planing tool should be made. These tools, tempered in the ordinary way, should without breaking or bending, cut the outside bed of a white iron casting. The Orleans Railroad requires that the rail should be forged from 20 to 30 mm. square, and be tempered so hard that they will break easily.

The fracture of the broken rail should have a fine uniform grain, and a much finer texture than before tempering. A piece of rail is then rolled out to 75 mm. in length, and 1 cm. thick, and made in the shape of a spring. The spring is laid upon supports and tested with a weight placed upon its convex side, in the middle. The spring should be capable of being lengthened 4 mm. per metre, without breaking. All the rails submitted to the test by shock should undergo this trial.

A provisional acceptance of the rail is made by the agents of the company at the works, and, so far as possible, as they are manufactured. The object of this is to sort, weigh, and mark all the rails which fulfil the stipulated conditions. All rails which, either in transportation, before or after being laid upon the road-bed, are broken within a certain specified time, must be replaced. The entire expense of the apparatus for making the tests, as well as the labor of receiving and testing the rails, is borne by the manufacturer. All the rails accepted are marked at their ends, and those which are rejected are also marked in a way that will effectually prevent their ever being used on the road-bed. All of these marks must be easily seen, and must be made in such a way that they cannot be effaced. The Northern Railroad requires a guarantee of the rails for six years from the date of their manufacture, whether they are employed on the direct line or upon switches. The Orleans Railroad especially provides that the guarantee shall not extend to rails laid in ballast quarries, or put down for the purpose of building any part of a new road.

Every rail that during this time is broken, or becomes deteriorated in any other way than by ordinary wear, must be replaced by the manufacturer. This exchange of damaged rails for new ones is effected at places indicated in the contract. At the Lyons Railroad, all rails which are broken or injured before 15,000 trains have passed over them must be replaced. Whatever may be the cause of the fracture, all the rails broken within a period of 3 years and 3 months after they are delivered must be replaced, or, if the manufacturer does not care to replace them, he may indemnify the company in money. In order to ascertain what this is likely to be, 5 per cent. of the rails delivered may be placed by the company on its line, on curves, or wherever else it shall be judged most convenient, and the manufacturer is notified of these places. At the expiration of the delay necessary for the passage of 15,000 trains, all the rails which show a commencement of deterioration, like crushing, want of proper

welding, exfoliation, fracture, etc., comprising those which have been already replaced, shall be noted.

The proportion which is fixed in this way, is applied to the entire order. The indemnity for every ton of rails, without taking into consideration rails which may still be used by being made shorter, is fixed by contract and is intended to represent the difference in value between a ton of the new rails and a ton of the rejected rails, both delivered in the depot nearest to the manufacturer; but the rejected rails, except the broken ones which are replaced, will remain the property of the company. The rails must be delivered on the cars at the railroad station nearest to the works of the manufacturer, or deposited in regular piles, which can be easily counted, at some other place, if so indicated by the contract. Transportation from the works to the place of delivery is in all cases to be made at the risk and expense of the manufacturer.

The payments are made at Paris. The Lyons Railroad pay 95 per cent. of the value of the rails at the end of a month after their delivery, the other 5 per cent. after their final reception. Both the manufacturers and the railway companies are exceedingly particular in their instructions with regard to the treatment of rails in transporting them on the cars, and particularly in discharging them from the cars; throwing the rails or allowing them to fall from any height being most positively forbidden.

The care of rails is, in some instances, even carried to excess. Some companies who distribute their rails at certain points along the road, in order to provide for possible accidents, house beside the track all the rails so distributed, in order to prevent oxidation. This housing is, certainly, very desirable in the winter-time, when the rails are likely to become frozen together, but it does not seem necessary for the cause assigned, for the danger from oxidation, except in contact with acid waters, is exceedingly trifling. The rails broken upon the road are usually brought to the workshops of the main office of the road, and the pieces tested. It is very rare that the pieces so tested do not resist a force superior to that required by the contract.

As an example of the way in which this testing is done, and the care which is taken to see that all the rails are up to the required standard, I give below two examples of the details of testing broken

rails. These experiments were made at my request, and in my presence, under the direction of Mr. Contamin, who had charge of that department, at the works of the Chemin de Fer du Nord, at Ermont, near Paris.

Both the rails tested were of steel, and had been broken on the road while I was in Paris, and were sent to the works at my request for the purpose. The first experiment was made upon a rail weighing 35 kg. per metre, manufactured at Creusot. This rail had been down one year. It was found broken 2.15 m. from one end. The fracture was uniform, and without blow-holes or dark spots. The lower part of the fracture on the foot of the rail was quite smooth, which seems to show that there had been more or less vibration at that point, and that the fracture had commenced there. Both pieces of the rail were tested. One of them was 5.75 m., and the other 2.15 m., so that the rail was originally 7.90 m. in height.

Test of the Piece 5.75 m. in length, broken on the Road.

The piece of the rail was placed upon supports 1.10 m. apart, and subjected to the fall of a weight of 300 kg. under the exact conditions of the contract, the results of which are given in the table below:

Height of fall,	1 m.	1.50 m.	2 m.	2.25 m.	2.50 m.	3 m.	3.25 m.
Permanent set,	1 mm.	7 mm.	16 mm.	24 mm.	33 mm.	44 mm.	broke.

The rail, when struck by the weight, gave out a silvery sound, and was so elastic that when struck from a height of 1.50 m., the weight rebounded several times at each stroke, and the rail turned bottom up in the supports, so that the head was down. The rail was always replaced in its proper position when it turned over. At the height of 3 m., the rebounding weight falling upon the rail which had turned when the weight first struck it, so that the foot of the rail was uppermost, but the rail was not horizontal, broke off a piece of the foot, for which reason the rail broke at that point at the next fall, which was 3.25 m. This piece of the rail was now broken into two pieces, which were 2.45 m. and 3.30 m. in length. Both of these pieces were tested.

Tests upon the piece 2.45 m. in length.

Height of fall, . .	1 m.	1.50 m.	2 m.	2.25 m.
Permanent set, .	4 mm.	10 mm.	22 mm.	broke.

It will be noticed that the permanent set here was much greater than in the case of the first piece, but the rail did not break until it arrived at the limit required by the contract. The fracture was light-gray, but dotted with small brilliant points which did not appear in first test.

Test on the piece 3.30 *m. in length.*

Height of fall,	1 m.	1.50 m.	2 m.	2.25 m.	2.50 m.	3 m.	3.25 m.
Permanent set,	3 mm.	5 mm.	10 mm.	16 mm.	20 mm.	28 mm.	broke.

It will be noticed that the set in this case is very much less than in the former tests. The piece was so elastic, that the weight rebounded from it, and from 2 m. onwards the rail turned over, after every stroke of the weight. The fracture was entirely regular, and similar to the fracture of the first piece.

TEST OF THE PIECE 2.15 M. IN LENGTH, BROKEN ON THE ROAD.

Height of fall,	1 m.	1.50 m.	2 m.	2 25 m.	2.50 m.	3 m.	3.25 m.
Permanent set,	6 mm.	16 mm.	36 mm.	54 mm.	74 mm.	98 mm.	120 mm.

The sound produced by the fall of the weight was not so sonorous as in the former cases. The rail did not turn over in its support, and the weight did not rebound until after the second shock, and then only once after each shock instead of several times as in former cases. When the flexure of the rail had reached 120 mm., it was so much bent, that it touched the bottom between the two supports. It was then turned over and straightened, by allowing the weight to fall upon the foot. After three successive shocks from a height of 3 m., the rail became perfectly straight, but at the last shock a piece of the foot 15 cm. in length was broken off. The rail was then placed with the head up, but the first blow from a height of 3 m. broke it. The fracture was clear gray without brilliant points, but appearing as if the crystals had been elongated. This test shows a very extraordinary resistance to rupture, within 85 cm. of the point where the rail broke upon the road.

This rail was thus broken five times, once upon the road and four times in these experiments. Although the resistance to rupture in the four experiments is very unequal, and the different parts of the rail seem not only to have a different resistance, but a different elasticity, they are all within the limits prescribed by the contract; and, therefore, in a commercial sense, the original fracture cannot be said to be owing to the inferior quality of the rail.

The fracture on the road was probably caused by an imperfection which was undoubtedly commenced in a small crack, probably produced either in straightening the rail, or in discharging it from the cars. The irregularity of the resistance was so great that I had pieces cut off near the breaking points of each one of the pieces of rails, preserving the fractured surface on one side. The other side I had polished so that it might be etched by acids. In this way I hoped to discover any irregularity of texture.

The other rail broken was manufactured at Terrenoire and had been in use 16.5 months. It was laid on the 16th of December, 1872, and taken up broken on the 15th of April, 1873. The fracture commenced in the body near the head, and just above the fish-plate holes, and extended from thence a short distance, parallel to the head of the rail, and then curved irregularly until it reached the foot, 40 cm. from the end of the rail. It was placed on supports as usual and broken.

Test of the Rail.

Height of fall, . .	1 m.	1.50 m.	2 m.	2 25 m.	2.50 m.
Permanent set, . .	2.8 mm.	6.7 mm.	12.1 mm.	17 mm.	broke.

The half towards the end which had been broken on the road was now placed between supports and broken.

Height of fall, . . .	1 m.	1.50 m.	2 m.	2.25 m.	2.50 m.
Permanent set, . .	2.9 mm.	6.7 m.	12.9 mm.	19.6 mm.	broke.

It will be noticed that the sets in this rail, with the exception of the last one, were almost absolutely identical. The rail appeared to be uniform throughout. The fracture showed a clear grain, somewhat larger than the rail from Creusot, with elongated crystals. Both pieces of the rail showed a resistance greater than that required by the contract, but it is still, however, in general, less than that which is shown by most rails which are broken, and less than that of the rails ordinarily furnished from Terrenoire.

It must be seen, as a result of these experiments, that so far as we are able to ascertain without chemical analysis, the probable cause of the fracture was in these instances improper handling of the rails. It certainly was not due to any defect in fulfilling the conditions of the contract.

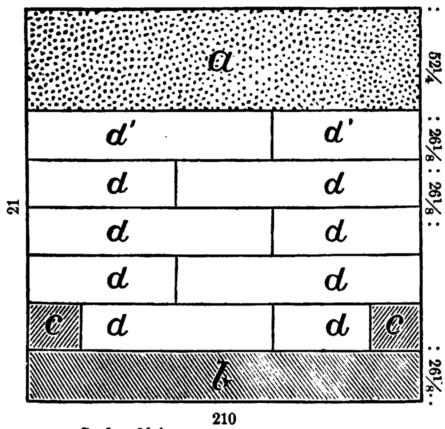
The following information, with regard to the method of piling

rails in Germany, was collected at my request by W. A. Smith, E. M., at that time attached to the United States Legation at Berlin:

KÖNIGSHÜTTE, IN SILESIA.

FIG. 1.

Dimensions in millimetres.



Scale of ¼.

a. Fine-grain tough head-plate, rolled out of a package of puddle-bars.
b. Foot-plate, rolled out of good tough puddle-bars.
c. Inserted bars, rolled out of good tough puddle-bars.
d′ d′. Soft fine-grain puddle-bars.
d d. Ordinary puddle-bars.

In the finished rail: the head is three times reheated iron, the web is once reheated iron, the foot is twice reheated iron.

These works guarantee the rails for three years on levels over which not more than 16,000 axles pass daily.

The package is heated, hammered under a 4.5-ton hammer, again heated, and rolled out to the finished rail. These rails are guaranteed for five years, provided not more than 16,000 axles daily pass over them. Rails with a fine-grained iron head are guaranteed for four years under the same conditions.

To form the head-plate *a* in Fig. 3, the package Fig. 2 is used. This is made of the best sorted puddle-bars, the side-plates—shaded in Fig. 3—being of once reheated iron rolled into the above form. In the head-plate, the longer edges of the original puddle-bars are placed vertically. The package Fig. 2 is heated, hammered under a 6-ton steam-hammer, and rolled out to *a*, Fig. 3. In Fig. 3, the plates *b b* are of once reheated good iron. This package, Fig. 3, is heated, hammered under a 6-ton steam-hammer, again heated, and

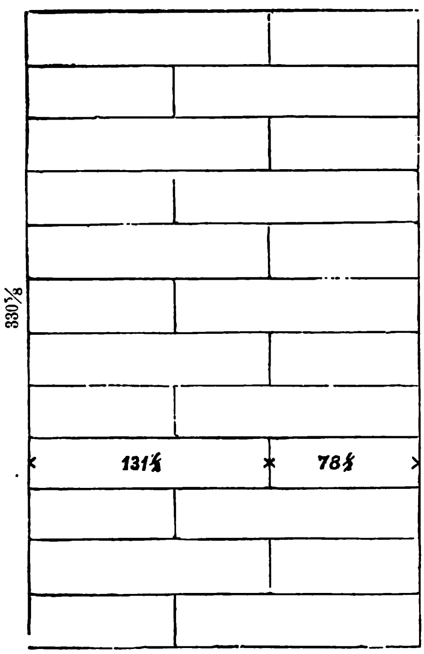
rolled out to the finished rail. These rails are guaranteed for three years in Germany only.

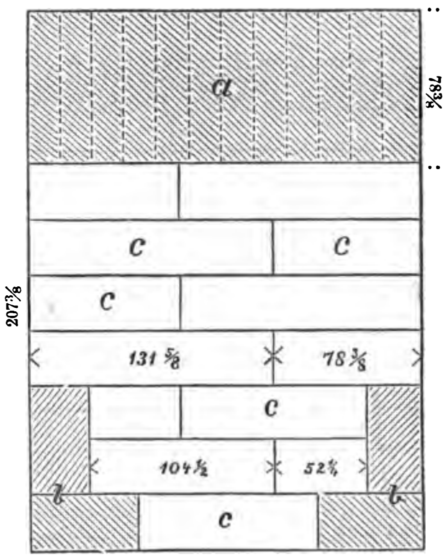
In case the head is of steel, the package is made in the same way.

GUTEHOFFNUNGSHÜTTE AT STERKRADE ON THE RHINE.

FIG. 2. FIG. 3.

Dimensions in millimetres.





Scale of $\frac{1}{4}$.

FIG. 2. Package of puddled steel bars which is rolled out to a bar of 0.210 m. $\times 0.078\frac{5}{8}$ to form the head plate *a* in Fig. 3. In the package, Fig. 3, and in the finished rail, the longer sides of the sections of puddle-bars would occupy a vertical position.

FIG. 3. *a* Steel head-plate, rolled out of puddled steel bars.
b. Twice reheated tough iron.
c. Puddle-bars.

The head-plate is rolled out of puddled steel bars; and, to secure a good weld, the bars *c c*, are of fine-grain puddled iron. The rails are guaranteed for five years in Germany only.

The shaded loupe-bars are of puddled steel, the others of tough iron. For the better formation of the foot of the rail, the bars *b b*, are of reheated tough iron. The package is twice heated and hammered under a 6-ton steam-hammer, is again heated and rolled out

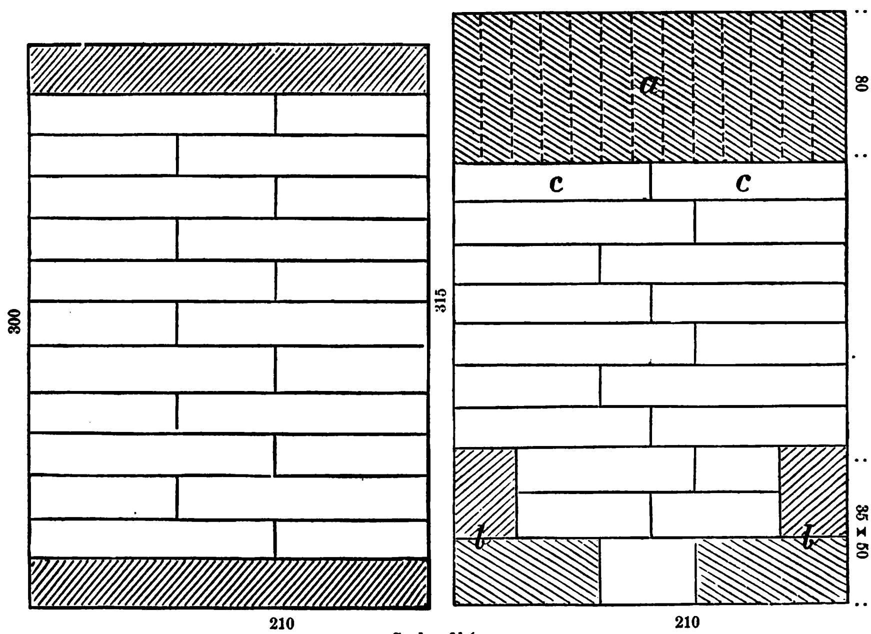
to the finished rail. After the second hammering, the package has a cross-section of 0.183 × 0.183 m. These rails are guaranteed for five years, provided they are not used about stations or on grades of 1.6 or above.

To form the head-plate *a* in Fig. 5, the package Fig. 4 is used. This is made of the best sorted puddle-bars, the side-plates,—shaded in Fig. 4,—being of once reheated iron rolled into the above form.

PHÖNIX EISENHÜTTEN-GESELLSCHAFT NEAR RUHRORT ON THE RHINE.

FIG. 4. FIG. 5.

Dimensions in millimetres.



Scale of ¼.

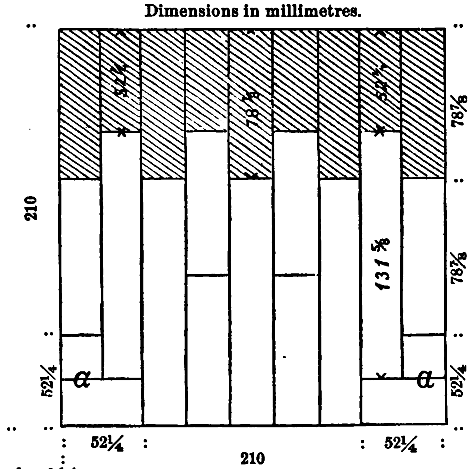
In the head-plate the longer edges of the orginal puddle-bars are placed vertically. The package Fig. 4 is heated, hammered under a 6-ton steam-hammer, and rolled out to *a*, Fig. 5. In Fig. 5, the plates *b b* are of once reheated good iron. This package, Fig. 5, is heated, hammered under a 6-ton steam-hammer, again heated, and rolled out to the finished rail. These rails are guaranteed for three years in Germany only.

In case the head is of steel, the package is made in the same way. The head-plate is rolled out of puddled steel bars; and to secure a good weld, the bars *c c* are of fine-grain puddled iron. These rails are guaranteed for five years in Germany only.

HOERDER BERGWERKS- UND HÜTTEN VEREIN, WESTPHALIA.

FIG. 6.

Dimensions in millimetres.



Scale of ¼.

The shaded loupe-bars are of puddled steel; the others of tough iron. For the better formation of the foot of the rail, the bars *a a* are of reheated tough iron. The package is twice heated and hammered under a 6-ton steam-hammer, is again heated and rolled out to the finished rail.

After the second hammering the package has a cross-section of 0.183 m. × 0.183 m. These rails are guaranteed for five years, provided they are not used about stations or on grades of 1.6 or above.

As it is important to ascertain the cause of fracture, in order to avoid it, I made an effort to get from all the roads a complete history of rails broken, as far as it was possible, and also to collect the records of the mean temperature of the month and year, and other details as to whether the rail was broken on the inside or outside of a curve of a given radius, or by a train going up or down a grade. Such a history was compiled for me by the Paris and Lyons Railroad, for three of its auxiliary lines, month for month, for the years 1869, 1870, 1871, and 1872, and merits a most careful and attentive study. The first and third of these roads used the iron double-headed rails, exclusively, up to the year 1872, when the Geneva line commenced by putting down 15½ kilometres of steel rails. The Tarascon line has used them since 1869, in small quantities at first, but gradually increasing them until, in 1872, there were twenty-one kilometres of steel rails on the line of the road. The St. Germain line had not used steel rails up to 1872.

Statistics of Rails broken per month on three of the Auxiliary Lines of the Lyons Railroad.

Line from Amberieu to Geneva.

Dates.	Descents.				Ascents.				Line with a radius of curvature.				Rails broken.			
	Above 0.008.	From 0.008 to 0.005.	From 0.005 to 0.002.	From 0.002 to ascents 0.002.	From 0.002 to 0.005.	From 0.005 to 0.008.	Above 0.008.	Straight line.	Above 500.	From 500 to 301.	From 300 and below.	Form of rail.	After being turned over.	Before being turned over.	Total.	Time that the rails were placed on the road.
1869.																
January...	....	1	....	....	....	....	....	..	1	......	......	D. C.	......	1	1	
February.	....	....	....	1	....	....	....	..	1	......	......	"	1	......	1	
March......	....	1	1	....	1	....	....	1	1	1	......	"	1	2	3	
July.........	1	....	....	....	....	....	....	1	......	......	......	"	1	......	1	1858.46
August....	....	....	....	1	....	....	....	..	......	1	......	"	1	......	1	
Septemb'r	....	....	....	....	1	....	....	..	1	......	......	"	1	......	1	
Novemb'r	....	....	....	1	....	....	....	..	......	1	......	"	......	1	1	
December	....	....	1	....	1	....	....	...	2	......	......	"	1	1	2	
Total, 1869	1	2	2	3	3	0	0	2	6	3	0		6	5	11	
1870.																
January...	1	1	....	2	....	....	....	1	3	......	......	D. C.	4	......	4	
February.	....	....	....	....	1	2	....	2	1	......	......	"	3	......	3	
March......	....	1	1	....	....	....	....	..	2	......	......	"	1	1	2	
April.......	....	....	....	....	....	1	....	1	......	......	......	"	......	1	1	
June........	....	....	....	1	....	....	....	..	1	......	......	"	......	1	1	1858.97
August.....	1	....	....	....	....	....	....	1	......	......	......	V.	......	1	1	
Septemb'r	....	....	....	....	....	....	1	1	......	......	......	D. C.	1	......	1	
October ...	1	....	....	....	....	....	....	1	......	......	......	"	......	1	1	
Novemb'r	....	....	....	3	1	....	1	..	4	1	......	"	3	2	5	
December	2	....	2	1	4	....	....	4	1	4	......	"	3	6	9	
Total, 1870	5	2	3	7	6	3	2	11	12	5	0		15	13	28	
1871.																
January...	3	7	10	7	5	2	4	17	15	6	......	D. C.	23	15	38	
February.	2	2	1	5	....	1	1	4	7	1	......	"	8	4	12	
March......	2	2	2	1	1	2	....	3	6	1	......	"	8	2	10	
April.......	1	1	1	....	....	1	....	1	2	......	......	"	8	......	3	
May.........	1	1	....	....	....	....	....	..	1	1	......	"	1	1	2	
July.........	1	....	....	....	....	....	....	1	......	......	......	"	......	1	1	1860.34
August....	1	2	....	....	....	....	1	2	2	......	......	"	3	1	4	
Septemb'r	....	....	....	....	....	1	....	..	1	......	......	"	......	1	1	
October...	....	....	....	....	1	....	....	1	......	......	......	"	1	......	1	
Novemb'r	....	1	....	3	....	2	....	3	3	......	......	"	5	1	6	
December	7	....	....	4	....	....	....	6	2	3	......	"	8	3	11	
Total, 1871	18	16	14	20	7	8	6	38	39	12	0		60	29	89	
1872.																
January...	3	....	....	1	3	2	2	3	4	4	......	D. C.	9	2	11	
February.	1	....	....	1	3	1	....	2	4	......	......	"	4	2	6	
March......	....	....	....	....	1	1	3	4	1	......	......	"	2	3	5	
April.......	1	1	....	1	....	....	1	1	1	2	......	"	2	2	4	
June........	....	....	....	1	....	1	....	1	1	......	......	"	1	1	2	
July.........	1	....	....	1	....	....	1	1	1	1	......	"	1	2	3	1862.01
August.....	....	1	....	1	....	....	....	..	2	......	......	"	2	......	2	
Septemb'r	1	....	....	3	....	....	....	4	......	......	......	"	2	2	4	
October ...	....	....	....	1	....	....	1	..	1	1	......	"	2	......	2	
Novemb'r	3	....	....	1	....	....	1	1	2	2	......	"	3	2	5	
December	7	....	....	1	....	...	2	3	4	3	......	"	9	1	10	
Total, 1872	17	2	0	12	7	5	11	20	21	13	0		37	17	54	

Line from Tarascon to Cette.

Dates.	Above 0.008.	From 0.008 to 0.005.	From 0.005 to 0.002.	From 0.002 to ascents 0.002.	From 0.002 to 0.005.	From 0.005 to 0.008.	Above 0.008.	Straight line.	Above 500.	From 500 to 301.	From 300 and below.	Form of rail.	After being turned over.	Before being turned over.	Total.	Time that the rails were placed on the road.
1869.																
February.	....	....	....	1	....	....	....	1	......	......	......	D. C.	1	......	1	
Novemb'r	....	....	....	2	....	....	....	2	......	......	......	"	2	......	2	1859.00
December	....	....	....	1	....	....	....	..	1	......	......	"	1	......	1	
Total, 1869	0	0	0	4	0	0	0	3	1	0	0		4	0	4	

Note.—D. C. signifies double-headed rail. V. signifies American rail.

Statistics of Rails broken per month on three of the Auxiliary Lines of the Lyons Railroad.

LINE FROM TARASCON TO CETTE.—*Continued.*

Dates.	Descents.				Ascents.			Straight line.	Line with a Radius of Curvature.			Form of rail.	Rails Broken.		Total.	Time that the rails were placed on the road.
	Above 0.008.	From 0.008 to 0.005.	From 0.005 to 0.002.	From 0.002 to ascents 0.002.	From 0.002 to 0.005.	From 0.005 to 0.008.	Above 0.008.		Above 500.	From 500 to 301.	From 300 and below.		After being turned over.	Before being turned over.		
1870.																
January...	....	....	....	1	....	....	....	..	1	......	......	D. C.	1	......	1	
February.	....	....	....	1	....	....	....	1	......	......	......	"	......	1	1	
March......	....	....	....	1	....	....	....	1	......	......	......	"	1	......	1	1860.00
July.........	....	....	....	1	....	....	....	1	......	......	......	"	1	......	1	
December	....	....	....	2	....	....	....	1	1	......	......	"	1	1	2	
Total, 1870	0	0	0	6	0	0	0	4	2	0	0		4	2	6	
1871.																
January...	....	....	....	2	....	....	....	1	1	......	......	D. C.	2	......	2	
February.	....	....	....	1	....	....	....	1	......	......	......	V.	......	1	1	
June........	....	....	....	1	....	....	....	1	......	......	......	"	......	1	1	1861.00
October...	....	....	....	....	1	....	....	..	1	......	......	"	......	1	1	
Novemb'r	....	....	....	1	....	....	....	1	......	......	......	D. C.	1	......	1	
Total, 1871	0	0	0	5	1	0	0	4	2	0	0		3	3	6	
1872.																
January...	....	....	....	1	....	....	....	1	......	......	......	D. C.	1	......	1	
March......	....	....	....	2	....	....	....	2	......	......	......	D.C.&V.	1	1	2	1862.00
December	....	....	....	1	....	....	....	..	1	......	......	V.	......	1	1	
Total, 1872	0	0	0	4	0	0	0	3	1	0	0		2	2	4	

LINE FROM ST. GERMAIN-DES-FOSSES TO BRIOUDE.

Dates.	Descents: Above 0.008.	From 0.008 to 0.005.	From 0.005 to 0.002.	From 0.002 to ascents 0.002.	Ascents: From 0.002 to 0.005.	From 0.005 to 0.008.	Above 0.008.	Straight line.	Above 500.	From 500 to 301.	From 300 and below.	Form of rail.	After being turned over.	Before being turned over.	Total.	Time that the rails were placed on the road.
1869.																
January...	....	....	....	1	....	....	....	.	1	......	......	D. C.	1	......	1	
February.	....	....	1	....	....	....	....	1	......	......	......	"	1	......	1	
October ...	....	....	....	1	....	....	....	1	......	......	......	"	1	......	1	1859.01
Novemb'r	....	1	....	....	....	....	....	..	......	1	......	"	......	1	1	
December	....	....	....	....	....	1	....	..	1	......	......	"	......	1	1	
Total, 1869	0	1	1	2	0	1	0	2	2	1	0		3	2	5	
1870																
February.	....	....	1	....	....	....	....	1	......	......	......	D. C.	1	......	1	
April.......	....	....	1	....	....	....	....	..	1	......	......	"	1	......	1	
October ...	....	1	....	....	1	....	....	2	......	......	......	"	2	......	2	1859.91
Novemb'r	....	1	....	1	....	....	....	1	1	......	......	"	1	1	2	
December	....	....	1	....	....	....	....	..	1	......	......	"	1	......	1	
Total, 1870	0	2	3	1	1	0	0	4	3	0	0		6	1	7	
1871.																
January...	....	2	....	....	....	....	....	1	1	......	......	D. C.	2	......	2	
February.	....	1	1	....	....	....	....	1	1	......	......	"	2	......	2	
April.......	....	....	1	1	....	....	....	1	1	......	......	"	2	......	2	
August.....	....	....	1	....	....	....	....	..	1	......	......	"	1	......	1	1860.95
October ...	....	1	....	1	1	....	....	..	2	1	......	D.C.&V.	2	1	3	
Novemb'r	....	4	....	1	....	....	....	2	3	......	......	D. C.	4	1	5	
December	....	3	1	1	....	3	....	1	7	......	......	"	7	1	8	
Total, 1871	0	11	4	4	1	3	0	6	16	1	0		20	3	23	
1872.																
January...	....	....	....	....	1	....	....	1	......	......	......	V.	......	1	1	
April.......	....	....	....	1	....	....	....	..	1	......	......	D. C.	......	1	1	
May.........	....	....	....	....	....	1	....	1	......	......	......	V.	......	1	1	
August....	....	....	....	2	....	1	....	2	1	......	......	D. C.	3	......	3	1862.00
October....	....	1	....	....	....	....	....	..	1	......	......	"	......	1	1	
Novemb'r	....	1	1	1	....	....	....	2	1	......	......	"	3	......	3	
December	....	1	....	....	....	....	....	1	......	......	......	"	1	......	1	
Total, 1872	0	3	1	4	1	2	0	7	4	0	0		7	4	11	

NOTE.—D. C. signifies double-headed rail. V. signifies American rail.

Recapitulation of Rails broken per year on the Auxiliary Lines of the Paris and Lyons Railway.

LINE FROM AMBERIEU TO GENEVA.*

	DESCENTS.				ASCENTS.				LINE WITH A RADIUS OF CURVATURE.				RAILS BROKEN.				
DATES.	Above 0.008.	From 0.008 to 0.005.	From 0.005 to 0.002.	From 0.002 to ascents 0.002.	From 0.002 to 0.005.	From 0.005 to 0.008.	Above 0.008.	Straight line.	Above 500.	From 500 to 301.	From 300 and below.	Form of rails.	After being turned over	Before being turned over.	Total.	Time that the rails were placed on the road.	Gross tonnage by kilometres, of single track, and by year.
1869	1	2	2	3	3	0	0	2	6	3	0	D. C.	6	5	11	1858. 46	474,272 tons.
1870	5	2	3	7	6	3	2	11	12	5	0	D.C.&V.	15	13	28	1858. 97	613,315 "
1871	18	16	14	20	7	8	6	38	39	12	0	D. C.	60	29	39	1860. 34	752,358 "
1872	17	2	0	12	7	5	11	20	21	13	0	"	37	17	54	1862. 01	848,974 "

LINE FROM TARASCON TO CETTE.

1869	0	0	0	4	0	0	0	3	1	0	0	D. C.	4	0	4	1859. 00	1,620,459 tns.
1870	0	0	0	6	0	0	0	4	2	0	0	"	4	2	6	1860. 00	1,661,000 "
1871	0	0	0	5	1	0	0	4	2	0	0	D.C.&V.	3	3	6	1861. 00	1,707,000 "
1872	0	0	0	4	0	0	0	3	1	0	0	D. C.	2	2	4	1862. 00	2,051,311 "

LINE FROM ST. GERMAIN-DES-FOSSES TO BRIOUDE.

1869	0	1	1	2	0	1	0	2	2	1	0	D. C.	3	2	5	1859. 01	587,359 tons.
1870	0	2	3	1	1	0	0	4	3	0	0	"	6	1	7	1859. 91	620,000 "
1871	0	11	4	4	1	3	0	6	16	1	0	D.C.&V.	20	3	23	1860. 95	650,920 "
1872	0	3	1	4	1	2	0	7	4	0	0	D.C.&V.	7	4	11	1862. 00	681,748 "

* As the road is composed of two tracks each rail supports only half the tonnage.

The following table shows the relative proportions of the different iron and steel rails laid down on these lines, and the relative proportions of iron rails broken in the four cold months, as compared with the eight others. It is remarkable to see, in this table, how much better the American rail resists than the double-headed.

The line from Amberieu to Geneva has in plan no curve with a radius inferior to 400 m., and in profile it has no elevation which exceeds 0.013. This line, therefore, represents the mean of the lines of large curves and small inclinations, and lines of large curves and great inclination.

It is traversed by two expresses daily, that of Geneva and that of Italy, which go at the rate of 50 to 55 km. per hour, and frequently at as high a speed as 75 to 82 km. The traffic is very great. Throughout the length of this line there is a very great variation in temperature in the different seasons. In summer, the temperature is 35° C. = 95° F., and the greatest cold of winter is —18° C. = 0° F.

Proportion between the Iron Rails broken and those laid on the Auxiliary Lines of the Lyons Railroad.

Dates.	Length of Single Track.				Length of rails respectively.		Number of rails.		Number of rails broken.				Proportion for 100,000.			
	Steel rails.	V. Iron rails.	D. C. Iron rails.	Total.	V.	D. C.	V.	D. C.	In Jan., Feb., Nov., and Dec.		For the other months.		In Jan., Feb., Nov., and Dec.		For the other months.	
									V.	D. C.	V.	D. C.	V.	D. C.	V.	D. C.
Line from Amberieu to Geneva.																
	kilometres.	kilometres.	kilometres.	kilom.	kilom.	kilom.										
1869	....	7.354	222.176	229.530	14.708	444.352	2,451	74,058	....	5	....	6	....	6.75	....	8.10
1870	....	18.837	210.693	" "	37.674	421.386	6,279	70,231	....	21	....	7	....	29.90	....	9.96
1871	....	45.887	183.643	" "	91.774	367.286	15,296	61,214	....	67	....	22	....	109.45	....	35.94
1872	15.655	63.225	150.650	" "	126.450	301.300	21,075	50,217	....	32	....	22	....	63.60	....	43.81
Line from Tarascon to Cette.																
1869	0.168	155.345	46.799	202.312	310.690	93.598	51,782	19,500	....	4	....	....	....	20.51	....	....
1870	6.689	161.860	33.763	" "	323.720	67.256	53,953	14,068	....	4	....	2	....	28.43	....	14.22
1871	8.231	171.082	22.999	" "	342.164	45.998	57,027	9,583	1	3	2	....	1.75	31.31	3.50	....
1872	21.190	171.486	9.636	" "	342.972	19.272	57,162	4,015	1	1	1	1	1.75	24.90	1.75	....
Line from St. Germain-des-Fosses to Brioude.																
1869	....	23.840	181.752	205.592	47.680	363.504	7,947	66,092	....	4	....	1	....	6.05	....	1.51
1870	....	37.706	167.886	" "	75.412	335.772	12,569	61,049	....	4	....	3	....	6.55	....	4.91
1871	....	57.472	148.120	" "	114.944	296.240	19,157	53,862	....	17	1	5	....	31.56	5.22	9.28
1872	....	61.893	143.699	" "	123.786	287.398	20,631	52,254	1	4	1	5	4.84	7.65	4.84	9.56

The *fracture* of iron rails only is given in this table.

The line from Tarascon to Cette is one of the lines of large curves and small inclinations. The speed is the same as for the Geneva line, but the quick trains are heavier. The traffic is great, though not as great as on the Geneva line. The temperature is rather hot than otherwise, and there is no very great amount of cold.

The line from St. Germain-des-Fosses to Brioude has a great many curves, a very large number of which have a radius inferior to 400 m., several of them below 300 m. The maximum inclination is not over 0.010. The least speed is generally 40 km. the hour, and the greatest is accidentally 60 km. The traffic is less than that upon the previous line; but about the same as that of the Geneva line. The temperature varies from 35° C. = 95° F. to —10° C. = 14° F.

It will be seen by the table given below that on the Geneva line, where the greatest cold occurs, by far the greater portion of the rails were broken, during the four years, in the months of January, February, and December; that on the St. Germain line, where the next lowest temperature occurs, they were broken in November and December; while on the line where the temperature is about equal, they were broken in January and December; or, in general, that the cold months are those in which the greatest number of fractures occur.

Recapitulation of the number of Rails broken per month on the Auxiliary Lines of the Lyons Railroad.

	Amberieu to Geneva.				Total.	Tarascon to Cette.				Total.	St. Germain-des-Fosses to Brioude.				Total.
	1869	1870	1871	1872		1869	1870	1871	1872		1869	1870	1871	1872	
January...	1	4	38	11	54	....	1	2	1	4	1	....	2	1	4
February.	1	3	12	6	22	1	1	1	....	3	1	1	2	....	4
March......	3	2	10	5	20	....	1	....	2	3	......	....	....	....	......
April.......	......	1	3	4	8	....	....	....	....	......	......	1	2	1	4
May.......	......	......	2	....	2	....	....	....	....	......	......	....	....	1	1
June.......	......	1	......	2	3	....	....	1	....	1	......	....	....	....	......
July.......	1	......	1	3	5	....	1	....	....	1	......	....	....	....	......
August....	1	1	4	2	8	....	....	....	....	......	......	....	1	3	4
Septemb'r	1	1	1	4	7	....	....	....	....	......	......	....	....	....	......
October....	......	1	1	2	4	....	....	1	....	1	1	2	3	1	7
Novemb'r	1	5	6	5	17	2	....	1	....	3	1	2	5	3	11
December	2	9	11	10	32	1	2	....	1	4	1	1	8	1	11

The same results are shown by the statistics which were collected for me by the Orleans Company for the years 1864 to 1872, which show as to the mean of all the years, that the greatest number of rails broken was in January, and that about the same number were broken in the months of February and December, March and November, and April and October. It then seems to increase in May,

to diminish in June, to increase in July, then suddenly to fall in August, to gradually increase again to its maximum in January.

Iron Rails broken, per month, on the Principal Roads on the Lines of the Orleans Company of France during the years 1864 *to* 1872:

Years.	Lengths of the principal lines. Kilom.	Number of Rails broken during the months of												Total.	Proportion of rails broken to the 100 kilometres of road.
		January.	Februa'y	March.	April.	May.	June.	July.	August.	Sept.	October.	Nov.	Dec.		
1864	3,343	113	94	72	61	58	45	45	50	53	54	98	77	820	21.3
1865	4,016	123	116	111	79	49	42	24	33	25	60	83	99	844	21.0
1866	4,265	110	86	91	74	66	52	51	50	48	95	101	125	949	22.2
1867	4.538	151	109	111	102	80	77	60	63	59	88	84	121	1,105	24.3
1868	4,796	153	126	126	96	57	35	38	56	45	62	78	98	970	20.2
1869	5,018	105	97	101	80	65	54	50	41	54	77	98	127	949	18.9
1870	5,241	123	132	96	72	62	32	37	34	35	69	130	104	926	17.6
1871	5,297	226	128	145	92	52	83	54	61	73	139	176	161	1,390	26.2
1872	5,380	248	169	166	102	91	61	46	48	47	88	127	140	1,333	24.7
Mean.	4,710	150	118	113	84	65	54	45	48	49	81	108	117	1,032	21.9

The following statistics were collected, at my request, with reference to two double-headed iron rails, No. 1 and No. 2, which were broken on the Lyons Railroad, sections of which were prepared for etching and were to have been examined. They are exceedingly interesting, as No. 1 shows an unusual life, though not so great as the life of some of the Belgian rails cited further on. The tonnage passed over it, however, was not equal to that required by the Northern Railroad for the best iron rails. No. 2 did not last so long as No. 1, but still much longer than the ordinary iron rail. The amount of tonnage which passed over it is very small. Rail No. 1 was 13 cm. high, 6 cm. in its widest part, and 20 mm. in the body of the rail. It weighed 37.50 kgs. per m. It was made at St. Jacques, Montluçon, was laid in December, 1862, and was broken January 12th, 1874. It was therefore 11 years and some days old. It was placed upon a straight line with an incline of 0.004.

The total amount of tonnage which passed over it, was 16,761,677 tons, as is shown year by year in the following table:

Rail No. 1.

Year.	Tons.	Year.	Tons.
1863,.	1,515,680	1869,.	1,665,115
1864,.	1,418,820	1870,.	768,658
1865,.	1,357,650	1871,.	1,767,651
1866,.	1,868,210	1872,.	1,856,831
1867,.	1,436,785	1873,.	1,952,948
1868,.	1,547,678	1874,.	125,676
	8,644,818	Total,	16,761,677

Rail No. 2 was 13.24 cm. high, 6 cm. in its widest part, and 18 mm. in the body of the rail, and weighed 36 kg. the metre. It was made at Fouchanbault, in March, 1868, and broken in July, 1873, after having been five years and two months in use. It was on a straight line with an incline 0.003, and the total tonnage which passed over it was 2,647,433 tons, as is shown year by year in the following table:

Rail No. 2.

Year.	Tons.	Year.	Tons.
1868,	338,407	1872,	480,583
1869,	531,952	1873,	262,695
1870,	527,050		
1871,	506,746	Total,	2,647,433

The Central Railroad of Belgium, is 591 kms. in length, and uses six different kinds of rails, whose weight, and the number of kilometres used of each, is given in the table below.

Kind of rail.	Weight per metre.	Lengths laid down in kilometres.
Double-headed, with each head alike,	37	18
" " " " " "	33	153
" " " heads of different size,	34	89
American rail,	37	252
" "	35	76
" "	17	3

Besides this there are 141 kilometres, not included in the above, on side tracks and switches. It is found every year, as will be seen by the table, that the quality, or rather the power of resistance of iron rails decreases, which may be due in part to increase in traffic. On this road the iron rails are usually guaranteed for three years. There were, consequently, in 1870, the rails furnished by the contracts of 1867-68-69 to be examined. The following table gives the result of this examination of the rails, made for the year 1870:

Year the rail was finished.	Years of wear.	Rails rejected on Contract No. 1.	Rails rejected on Contract No. 2.	Rails rejected on Contract No. 3.	Mean for the year.
1867	3	*10.63 per ct.	*31.22 per ct.	.....	13.89 per ct.
1868	2	†31.26 "	*42 28 "	.....	34.39 "
1869	1	*2.76 "	*3.33 "	‡0.89	2.88 "

* Hammered. † Rolled ‡ Steel

The contract No. 3, for the year 1869, was for Bessemer steel rails, which are guaranteed for seven years, and had six years yet to run. It shows an exceedingly small proportion of rejected rails. The contracts No. 1 and 2, for all the years, were for iron rails. The guarantee for iron rails is for three years, but in order to ascertain exactly how the rails wear out, the revision is made every year, and kept up each year after the term of guarantee expires. The following table gives the results of the revision of iron rails made in 1870, for each year from 1865 to 1869:

Situation of Iron Rails, guaranteed for three years, on the Grand Central Railway of Belgium, in the year 1869.

Year the rail was laid.	Number of years of service.	Percentage of rails taken up.	Percentage of rails damaged.	Total percentage of rails taken up or damaged.	Percentage of good rails remaining upon the road.
1865	5	58.92	18.62	77.54	22.46
1866	4	43 99	20.79	64 78	35.22
1867	3	2.55	11.34	13.87	86.11
1868	2	6.15	28.24	34.39	65.61
1869	1	0.29	2.59	2 88	97.12

Comparing these figures with those found as a result of the revision of 1869, the following result was found for the year 1870:

Situation of Iron Rails, guaranteed for three years, on the Grand Central Railway of Belgium, in the year 1870.

Year the rail was laid.	Number of years of service.	Percentage of rails taken up.	Percentage of rails damaged.	Total percentage of rails taken up or damaged.	Percentage of good rails remaining upon the road.
1865	6	17.77	8.25	26 02	73 98
1866	5	36.20	6.66	42.86	57.14
1867	4	1.88	8 61	10.49	89 51
1868	3	5.00	17.58	22.58	77.42

The revision of the rails laid down in 1867, at the expiration of the three years' guarantee, gave very different results for the two works which furnished the iron rails, as is seen by the table, the one giving a loss of 31.22 per cent., and the others a loss of 10.63 per cent. The first of these are rails which were rolled, while the others were hammered. Of the 10.63 per cent. rejected of the hammered rails, there were only 1.37 per cent. which required to be removed from the road-bed. The other 9.26 per cent., although rejected, did not need to be taken up. They can still be used for a long time on the road. The greatest confidence in these hammered

iron rails is expressed by the Belgian engineers, as being far superior to any of those which are rolled.

Of those which were laid upon metallic ties, at the end of three years' service, there were only 2.49 per cent. rejected, and not a single one of these was taken off the road. Of those which were laid upon ordinary ties of wood, there were 12.44 per cent. rejected, of which 1.76 per cent. had to be taken off the road altogether. As these rails are placed in positions which are identical, and were made by the same works, the difference in wear can only be attributed to the greater stability of the road-bed due to the use of metallic ties.

The results of the examination of the rails laid in 1868, after being down two years, are very bad, but this was expected, as they showed very bad wear, after one year's use, resulting from very defective manufacture. This defect having been remedied, the hammered rails for 1869 showed only 2.76 per cent., and 3.33 per cent. rejected, or for the year only 3 per cent.; of which only 0.30 per cent. were removed from the road-bed. Whatever may be said in favor of these hammered rails, they are not to be compared with Bessemer steel rails, which after one year of use showed only 0.89 per cent. of rejected rails, not one of which had to be taken up. It will also be seen by the tables, that the number of rails taken up relatively to those which are damaged, increases very rapidly from year to year. Thus after one year, about 10 per cent.; after two years, 18 per cent.; after three years, 18 per cent.; after four years, 19 per cent.; and after five years, 79 per cent. of the damaged rails remaining on the road were taken up. It will be seen by these tables, that there remained upon the road-bed, in 1870, only 22 to 35 per cent. of the rails laid down in 1865 and 1866, that is to say, that the life of these iron rails was only four or five years. These facts, taken in connection with the results shown in all the comparative tests between iron and steel rails, seem to show that it is extravagant to use iron rails under any conditions.

The Belgian engineers speak in the highest terms of metallic ties, and were making a great many experiments upon the subject, the results of which have not reached me. They were tried extensively in Germany, and I was informed by the engineers at Krupp's works that they had definitely abandoned the use of wooden ties. I noticed, in 1873, that some of the German roads near the French frontier, which had commenced to use them, had taken them up, but I could not ascertain the cause.

I am indebted to Mr. G. Schorn, Government Engineer of Mines

at Liège, Belgium, for the following statistics with regard to the life of iron rails on the state railways of Belgium, for the year 1869. These statistics are particularly interesting, since they give not only the life of the rails but the total amount of passenger and freight traffic over the road for the year. It is, however, always a vicious practice, to give the life of a rail in years, for this does not necessarily signify anything, for it is evident that a rail may be laid in some part of the road where there is not much traffic, and consequently may last indefinitely. The only proper way to express the life of a rail, is by the number of tons traffic which has passed over it.

The rails which are used on the state railways of Belgium are of five kinds; two kinds of T-rails, two kinds of double-headed rails, and the ordinary American rail. The T-rails are of iron, and have the stem below the head, either undulated or straight, and are laid in cast-iron chairs, which support nearly the whole of the vertical part of the T. These T-rails were the first kind of rails ever manufactured, and as they were made at a time when cheap rails were not so much sought for as now, it is not at all surprising to see that they have a life which no rail made in modern times has ever yet attained, though it is quite probable that the steel rails will outlast them. Such rails as these were formerly used in this country, and have given results quite similar to these which are given abroad.

The double-headed rails are either symmetrical, or not symmetrical. The fifth kind of rail is of the ordinary American pattern, which they had commenced to use eight years previous. These rails are laid upon ties which are 0.90 m. apart, that is to say, there are 1760 ties for an English mile, instead of 2640 ties, as is commonly the case in the United States.

The following table gives the weight, per metre, of these different rails:

Weight, per metre, of the Different Rails used on the State Railways of Belgium, in 1869.

T-rails with a curved stem,	19 to 22	kil.
T-rails with a straight stem,	25 to 27	"
Double-headed rails with symmetrical heads,	38.5	"
Double-headed rails with dissimilar heads,	34	"
Ordinary American rail,	37	"

The following table gives the number of passengers, first, second, and third class, carried by express, ordinary, and special trains over the road, showing a total traffic, over a road 863 km. in length, of 13,500,000 passengers:

Passenger Traffic on the State Railways of Belgium for the year 1869.
Total Length of the Road, 862,666 *km.*

Number of Passengers Carried during the Year.

By Express trains,	First class,	383,749	1,407,881
	Second class,	353,841	
	Third class,	670,291	
By Ordinary trains,	First class,	554,681	11,803,682
	Second class,	1,564,238	
	Third class,	9,684,759	
By Special trains,	Children,	135,495	365,453
	Soldiers,	109,598	
	Civilians,	120,365	
			13,577,016

The following table gives the total quantity of freight carried over the same road, for the same year:

Quantity of Freight carried during the year 1869, *on the State Railways of Belgium.*

First class,	382,790	tons.
Second class,	414,280	"
Third class,	546,296	"
Fourth class,	1,724,911	"
Special freight,	780,037	"
Freight transported at a reduced price,	95,103	"
Freight by contract,	78,000	"
Total,	4,021,417	"
Smallest quantity sent at any one time,	103,172	"

The following table shows the entire distance, in kilometres, which every kind of train traversed:

Distance traversed by every Class of Trains during the year 1869, *on the State Railways of Belgium.*

Passenger trains,	Ordinary,	3,880,866 km.	5,069,001
	Express,	1,145,010 "	
	Special,	43,125 "	
Freight trains,	Special,	295,946 "	4,569,976
	Ordinary,	4,274,080 "	
	Total,		9,638,977

The following table gives the number of kilometres of traffic, which the rails, taken up from the road, supported. It is very interesting to notice, in this table, that the service of the rail gradually increases up to thirteen years, and then gradually diminishes, until it amounts to almost nothing; but even this life of thirteen years is most extraordinary for an iron rail, even though the amount of service, during this time, should not have been so very high. The number of tons carried over each rail is wanting. It is, however, necessary for the proper interpretation of the table, although supposing the service of the rails to have been the same in all cases, as it undoubtedly was, a relative view of the life of the rails is shown in it:

Wear of Rails taken up from the State Railways of Belgium in 1869.

Number of years of service.	Length of rails in metres.	Number of years of service.	Length of rails in metres.
½	1,363	16	238,937
1	4,417	17	299,185
2	11,128	18	205,542
3	9,703	19	144,302
4	29,397	20	75,007
5	67,803	21	40,454
6	125,278	22	17,668
7	95,051	23	23,432
8	120,999	24	21,050
9	143,272	25	8,697
10	171,638	26	5,709
11	354,804	27	3,384
12	403,159	28	3,653
13	496,419	29	1,401
14	417,292	30	919
15	333,261	31	1,194
	Total, ...		3,870,518

The following table gives the service already rendered by the rails remaining upon the road. The increase is much less regular than in the previous table, although it is very noticeable, that after thirteen years it diminished, though not so regularly as in the former case.

Wear of the Rails remaining on the State Railways of Belgium in 1869.

Number of years of service.	Length of rails in metres.	Number of years of service.	Length of rails in metres.
½	297,224	16	56,270
1	288,834	17	65,764
2	621,404	18	8,932
3	491,198	19	5,234
4	233,933	20	37,991
5	176,004	21	8,134
6	196,380	22	213
7	232,924	23	29,266
8	196,908	24	1,000
9	157,539	25	320
10	143,842	26	815
11	120,027	27	8,262
12	204,048	28	1,121
13	465,107	29	1,121
14	219,365	30	1,744
15	98,795	31	10,009
Total, ...			4,378,607

The following table gives the mean life of the rails taken up from the road, and shows the very remarkable result, that the old-fashioned T-rail and the double-headed rails, with unequal heads, have a life of 13 years. This applies, however, to rails manufactured when quality was more sought for than quantity, and we see immediately in the modern rails a diminution in life of from ½ to ⅔. The same superiority in the American rail being remarked that has been noticed elsewhere:

Mean Life of Rails taken up from the State Railways of Belgium, in the year 1869.

	Years.	
T-rails with a curved stem, ...	13	Mean life, the length of each particular kind of rail being taken into consideration, 13⅓.
T-rails with a straight stem, ...	13⅔	
Double-headed rails with dissimilar heads, . .	13⅘	
Double-headed rails with symmetrical heads, .	4⅓	
Ordinary American rails, ...	$6\frac{9}{11}$	

The following table gives the life of the rails remaining upon the road in the year 1869, and gives the same extraordinary results for the T-rails, and shows the great economy of making a first-rate article. For the first-class these rails have attained the extraordinary life of 23½ years.

Life of the Rails remaining on the State Railways of Belgium, in 1869.

	Years.	
T-rails with a curved stem,	$23\frac{1}{4}$	Mean life, the length of each particular kind of rail being taken into consideration, $\frac{7}{10}$.
T-rails with a straight stem,	$20\frac{9}{10}$	
Double-headed rails with dissimilar heads,	$7\frac{1}{4}$	
Double-headed rails with symmetrical heads,	$4\frac{5}{7}$	
Ordinary American rail,	$8\frac{7}{9}$	

I was particularly struck with the importance attached in France, to having no repairs of any kind done to the rails by the manufacturer. The conditions of the contract are such that it is contrary to his interest to make them, or to attempt to conceal in any way any defects. I had seen so much of this kind of repair done in Germany and elsewhere, but particularly in Germany, that this condition attracted my special attention. In one of the German works, the engineer who accompanied me, pointed out with special pride the skill with which they were able to putty up defects, and stated to me that the composition and method of doing it was a secret, and that special workmen only could do it. The defects were certainly thoroughly concealed, and it required very close inspection to discover cracks which had been cut out with a hammer and chisel, or with a file, and filled up with the composition, and there was very little probability that they would be discovered, even if they were sought for in the inspection. But it is very much like trying to cure the symptoms without attacking the disease. In other works, both in this country and in Europe, no attempt whatever is made to conceal, nor apparently to prevent, these defects, and I have seen very large piles of rails ready for delivery, not a single one of which, so far as I could discover, was without what appeared to be serious defects in the flange. These rails were besides cut, punched, and nicked, cold. I do not know where they were laid, but I was quite prepared to hear from a large railway house that the life of certain rails, which laid on an ordinary road-bed without accidents or unusual wear, did not exceed 18 months.

Almost all the companies in Europe have rail repair shops for iron rails, and very ingenious machinery, which is usually copied from American works, and often conducted by Americans. In these works, defective rails removed from the road-bed are repaired. It is evident that the companies have a great advantage in doing this, since in most cases, rails which are only damaged, remain the property of the company, but must be paid for by the manufacturer,

under the stipulations agreed upon in the contract. These repairs usually consist in putting in pieces, to fill out the rail where it has been damaged. In most cases these pieces are put into the head at the ends of the rail, but they sometimes require to be put in the head in the middle of the rail, and occasionally any other parts are replaced in the same way. The furnaces used for doing this work are so constructed, that the rail may be heated in any part independently of the other. The pieces to be put in are fastened with strong wire to the rail, which is then heated at that point, and passed through rolls so adjusted, that they may bear only on the point heated. This requires very great skill in the workmen, much more skill than time. When the ends are pierced, the pile is arranged in such a way as to make the rail too long, and it is afterwards cut to length, in order to have a perfect end. When the rails are not badly damaged, and are properly repaired, they look well, and can be very profitably used on turnouts or any other part of the road where they are not exposed to very great wear. Steel rails are never repaired, for the only accidents that ever happen to them is breakage, and then they are replaced by the manufacturer.

Steel rails have, of late years, been very generally adopted by the leading companies of this country and Europe. The fears expressed with regard to their not being able to resist the influence of the climate of this country, have proved to have been entirely groundless. The Central Railroad of Belgium commenced to use them in 1869, in the part of their road where *no* iron rails stood the test, with the most satisfactory results. It was at first feared that the steel rails would become rapidly polished, and that the locomotive would, consequently, have less adherence, and that the brakes would necessarily act less perfectly; but all these fears were proved to be without foundation, though steel rails do certainly become polished much more rapidly than iron.

The Northern Railway of France adopted, in 1873, a steel rail of the American pattern, which weighed 30 kgs. per m., made at Terrenoire and at Creusot. The normal length of this rail is 8 m., but in order to facilitate the manufacture lengths of 5, 6, and 7 m., are also admitted. The strength of this rail, in comparison with the types of all the rails in use on the principal roads of Europe, is shown in the table below. The limit of force exercised on the fibres of the top of the head of the steel rail, of 30 kgs., and the iron one of 37 kgs., when new, are represented for the steel rails by $\frac{V}{I} = 7.742$, and for the iron by $\frac{V'}{I'} = 7.012$. The ratio of these two

values is $\frac{7.742}{7.012} = 1.104$. For the base of the foot, the forces are 7981 for steel and 6472 for iron, whose ratio is $\frac{7.981}{6.472} = 1.233$.

If these same forces are calculated for the steel rail nearly worn out, and the new iron rail, the ratios are found to be $\frac{9689}{7012} = 1882$ for the head, and $\frac{9100}{6472} = 1406$ for the foot. For the new rail the greatest increase of force is less than 0.25 of the primitive values, and for the steel rail worn as far as it can be used, the greatest increase of the interior force, with regard to those of a new iron rail, is less than the 0.041th part of the primitive values. The limits of elasticity of steel are, however, double that of iron, so that the steel rail which is worn out, or has arrived at the limit of greatest wear, is still stronger than a new iron rail. These figures apply to the charge supposed to be at rest on the rails. If the charge is supposed in motion, it is found that the forces are increased only 0.264 for new steel rails, while for iron rails they are increased 0.301, and that when the steel rail has arrived at its maximum use, it is only 0.34; so that, notwithstanding its light weight, the steel is better than the iron rail. For the resistance to friction it is found that if T represents the force tending to cut it, $s = 743$ T for the steel rail of 30 kg. and $s = 662$ T for the iron. This increase is, however, fully compensated by the increased resistance of the steel, as the increased strain does not exceed, in effective force, more than 5 kg. per square millimetre.

Investigations, made by the Northern Railroad of France, with regard to the life of steel rails, show that the period, though very variable, unlike iron rails, depends directly upon the amount of weight carried over them. It has been ascertained that the steel rails wear out slowly in parallel layers, while iron rails deteriorate very rapidly, and are worn out before they have lost any very great amount of their weight by wear. In order to ascertain exactly what the wear is, a cast in plaster of the rail before it is laid down is taken, and after a certain number of million tons have passed over it, it is taken up and another cast is taken. The difference is then measured and gives the wear of the rail, per million tons, in millimetres. It has been found, after some years of experiment, that the *very best* iron rails do not last on this line for a circulation of over 20,000,000 tons, while *ordinary* iron rails will not last for over 14,000,000. All the experiments, however, show that steel rails wear uniformly a millimetre for a circulation of 20,000,000 tons, and as the rails now in use are calculated for a wear of 10 millime-

tres, we can suppose, accidents being left out of consideration, that the steel rail will not wear out before 200,000,000 tons have passed over it, that is to say, that the ordinary steel rail is ten times better than the best iron rail.

The temperature at which the steel rails are finished, has, of course, a great deal to do with its strength, and consequently with its life, and too little attention has been given to this subject. A great many experiments made with the object of comparing the two kinds of rails have shown, that in all the experiments on pressure, iron rails preserve a very appreciable permanent set, as soon as the compression attains 17 or 18 kgs. per square mm., while in steel rails this deformation does not commence until about 38 kgs. In the experiments upon direct traction, iron rails of good quality have a resistance of between 28 and 36 kgs. per square mm. Steel rails have a resistance between 65 and 70.

In the experiments upon shock, iron rails do not resist a force greater than 400 kilogrammetres, while for steel rails this resistance is about 900 km. Another great advantage of steel over iron rails is, that as they are made of a homogeneous material, when they are worn out, they are worth the full value of the steel contained, as steel to be remelted, while the iron of old rails not being homogeneous, but being composed of materials which are essentially different, more especially when the head has been made of iron containing phosphorus, is worth but little. The conditions of the contracts however, are generally such as to preclude the use of old iron rails, in any quantity, in the packages for the new ones.

The substitution of steel rails for iron, in France, has corresponded at once to a very considerable economy in the care of the road, at the same time that it gives greater resistance and security. For all these reasons the Northern Railway of France has adopted the steel rail of 30 k.*

These rails are not only stronger and better, but are actually cheaper, metre for metre, than the old iron ones of 37 kg. were, as shown by the table on the next page.

It is more than probable that the same results will hold good elsewhere. In this country, such a result would diminish the expenses for repair of the road, by increasing the life of the rails, so as in some cases to make it possible to run roads, now working

* This rail is made heavier than the steel rail usually adopted in the United States, which is 27 k. In Turkey for the main lines they use a steel rail of 25 k.

Comparison of the cost price of a kilometre of road laid with Iron Rails of 37 *kilogrammes, and of Steel Rails of* 30 *kilogrammes.*

	Iron rails of 37 kilogrammes.			Steel rails of 30 kilogrammes.		
	Quantities	Price.	Cost.	Quantities	Price.	Cost.
	Tons.	Francs.	Francs.	Tons.	Francs.	Francs.
Rails, ...	74.	350	25,900.	60.	420	25,200
Fish-plates, ...	3.20	350	1,120.	2.325	350	813.75
Bolts, ...	.562	530	297.86	.420	530	222.60
Screws, ...	1.685	650	1,095.25	1.580	650	1,027.
Wedges for rail ends, .	.032	578	18.50	.024	578	13.87
Ties, ...	1.167	5	5,835.	1.125	5	5,625.
Care of the road, transportation, cost of storage, which is 35 francs the ton of iron or for	79.479	35	2,781.76	64.349	35	2.252.21
Cost of a kilometre of single track, . . .	. . . .	. . .	37,048.37	. . . .	. . .	35,154.43
Excess of the cost of iron over the steel, per kilometre, ...	. . . .	. . .	. . . . .	. . . .	. . .	1,893.94
Or per metre in round numbers, ...	. . . .	. . .	. . . . .	. . . .	. . .	1.90

either without profit, or at a loss, and it is very desirable that statistics should be collected on this subject.

In changing the weight of the steel rail on the Northern Railroad it was necessary to take into account, that there were a large number of old iron rails still in use upon the road, and it was therefore desirable to make the steel rail of 30 k. of the same height as the old iron rail which weighed 37 k. Taking this as a starting-point, it was necessary to make the head of the rail as large as possible, and to reduce its body and the width of the foot as much as would be safe, in order to have the greatest amount of material in the head, as upon the depth of this part of the rail, other things being equal, its life depends, since steel rails wear out proportionately to the amount of traffic. That this has been done wisely, is shown by the wear of the rail on the road, and by the following table prepared by the Northern Railroad for the purpose of instituting a comparison between the rails of this road and those in use upon all the principal roads of Europe. It shows a number of very interesting comparative results.

The steel rail of 30 kgs. adopted by the Northern Railroad, is supported at 9 points. Near its joints the supports are 60 cm. apart, next to these 90 cm., and at all other places one metre. They are all fished, the holes for which are 0.024 m. in diameter, and are

Comparison of the Size and Strength of the different Rails used on the principal roads in Europe.

Name of rail.	Width of the head in mm.	Width of the stem in mm.	Width of the foot in mm.	Total height of rail in mm.	Section.	Weight, Iron = 7,600 Steel = 7,825	I.	Distance from the top to the mean line.	Distance from the foot to the mean line.	$\frac{V}{I}$ top.	$\frac{V}{I}$ foot.	$\frac{I}{V}$ top.	Relation between height and base.
					sm.	kgs.		m.	m.				
Northern Railroad, iron rail of 37 kgs..............	62	17	105	125	0.004895	37.202	0.00000927	0.065	0.060	7,012	6,472	0.000142	$\frac{125}{105}$=1.190
Northern Railroad, steel rail of 35.360 kgs........	59	14	102	125	0.004525	35.408	0.00000878	0.0652	0.0598	7,427	6,810	0.0003146	$\frac{125}{102}$=1.225
Northern Railroad, steel rail of 30.300 kgs........	56	12	97	125	0.003871	30.292	0.00000795	0.0615	0.0635	7,742	7,981	0.000129	$\frac{125}{97}$=1.288
Northern Railroad, iron rail of 30 kgs..............	58	14.8	95	113	0.003990	30.324	0.00000646	0.0578	0.0552	9,249	8,832	0.000108	$\frac{113}{95}$=1.190
Lyons Railroad, steel rail, pattern P. M........	60	16	130	130	0.00511	40.	0.00001137	0.0702	0.0598	6,172	5,260	0.000162	$\frac{130}{130}$=1.000
Lyons Railroad, iron rail, pattern P. L. M...	60	16	100	130	0.00475	36.123	0.00001019	0.06604	0.06396	6,464	6,270	0.000154	$\frac{130}{100}$=1.300
Eastern Railroad, iron rail	60	15	99	120	0.004596	34.540	0.00000823	0.06205	0.05799	7,539	7,035	0.000132	$\frac{120}{99}$=1.212
Cologne, Minden Co., iron rail.....................	58.5	14	914	124	0.004322	32.347	0.00000850	0.0635	0.0605	7,472	7,118	0.000133	$\frac{124}{91.4}$=1.356
Southern Railr'd of Austria, with heavy grade	57	13	104	122	0.00396	steel, 31.050	0.00000840	0.0644	0.0576	7,666	6,852	0.000130	$\frac{122}{104}$=1.173
*Railroad around Vienna. (Experiment.).....	53	16	99	79	0.00307	steel, 24.022	0.00000294	0.0451	0.0339	15,340	11,530	0.000065	$\frac{79}{99}$=0.798
†Northern Railroad of Austria, steel rail.......	57	13	110	120	0.003928	steel, 30.736	0.00000763	0.0636	0.0564	8,335	7,392	0.000120	$\frac{120}{110}$=1.091
‡State Austrian Railroad, steel or iron rail	62	17	105	125	....	....	....	....	....	....	....	....	$\frac{125}{105}$=1.190

* Test made upon a very small number of rails.
† This rail has been used since 1866 on Northern road of Austria.
‡ This rail differs very little from the type of 37 kgs. on the Northern Railroad.

bored. They are placed directly upon the ties, in places which are cut out for them, and are fixed by two spikes of galvanized iron for the intermediate ties, and with four for the joints. In order that the spikes shall not split the ties at the ends of the rails, they are not placed opposite to one another. Particular instructions are given, that every care shall be taken that the spikes shall not be placed in any pre-existing crack in the tie, nor in such a way, that they will interfere with spikes placed against the end of the rail. These spikes or wedges, are placed at one end of the rail, only to prevent it from slipping, leaving the other extremity free for movements of dilatation. To avoid the tendency of the rail, in all soft wood, to shove the outside spike, a cast-iron ring 2.50 cm. in thickness, with several projections on its outside diameter, is let into the tie, and the spike is driven through it, care being taken that there shall be at least 4 mm. between the upper part of the ring and the lower part of the rail. They are now trying the experiment of not placing the ends of the rails upon the same ties, but either on the next, or on a tie at some distance, so that the joint on one side of the track, will be either opposite a point near the end, or the middle of the rails on the other. The result is, that as the shocks due to the passage over the joints, are not simultaneous, their action upon the movement of the car is much less perceptible, and the road is much smoother. This method has not been long under trial, but there seems to be a considerable decrease in wear and tear.

A large series of both iron and steel rail ends, cut off near the point of fracture, collected from all the different roads, under varying circumstances, were prepared for etching, in order to study how far the fracture might have been caused by bad welding, or other defects, which entirely escape all ordinary inspection, and to ascertain whether, in the case of steel rails, there was any concentration of material, as has been suggested, near the point of fracture, which would tend to make the rail brittle at that point. Very little attention is paid to this subject of etching, in tests for iron and steel, much less than it deserves. It was hoped that important discoveries with regard to the causes of fracture of the rails would be made, that many of the points which are now not understood would be partially if not wholly explained, by the developments, either of concentrations of impurities, or physical defects, which cannot be made visible in any other way. The chemical constitution also of the rail is a subject which demands the most serious attention, more especially as it is now known that the relative proportions, more

than the amount, of certain substances, influence the strength of both iron and steel. Unfortunately the panic of 1873 prevented the execution not only of the analyses of the large collections of pieces of broken rails made for the purpose, but also all the other chemical and physical experiments which had been planned, and for some of which instruments had been devised.

Investigation seems to show that the fracture of almost all the broken steel rails started in defects which escaped the observation, but which were in the rail when it was laid. These defects, if not in the rail when delivered to the company, are generally caused, to a very great extent, by the rail being thrown from the car to the ground, or by other rough handling. The cases where sound rails are broken by the trains are comparatively rare. It is very noticeable, that the percentage of steel rails broken soon after they are laid, is exceedingly small, and that, up to a certain time after they have been down, it seems to increase, and then gradually to be reduced to almost nothing. This is owing to the fact that the fissures or cracks which escape observation, require some time to be developed sufficient to cause rupture, and that this time having been reached, a large number of rails break, and then, after these causes cease to operate, the defective rails being for the most part removed, the normal wear is shown in the sound rails that remain. In rails broken within six months after they were laid, it is generally easy to see that the fracture commenced in a small flaw and propagated itself, from the fact that the crack is, more or less, rusted where the break commenced. This cannot, however, be verified in all cases, because the rail is often allowed to lie for some days beside the track, instead of being always taken up and sent immediately to the workshops, although instructions are generally given, that whenever a rail is found broken, it shall be transported at once to the nearest station, to be sent to the workshops of the headquarters of the road, to be tested.

The holes for the fish-bolts, in rails of any kind, but particularly steel rails, should never be punched, as minute fissures are likely to be developed in the circumference of the holes;* nor should they, for the same reason, be notched in the flange. It is found that a very large percentage of punched and notched rails break shortly after

* It is asserted that the fissures produced in the circumference of the holes are so short, that they can be entirely removed by subsequently reaming out the holes. This saves the expense of drilling, and is now under trial in some of the French works.

they have been laid. Hence all the roads stipulate that all steel rails which are to be fished, should be bored, and that on no account should any change in the condition of the rail be made, after it has once passed through the rolls, except directly at the ends. It has been ascertained, by careful examination of the facts, that careless handling of the rails is one of the most frequent ways in which the small fissures, which eventually cause their fracture, are produced, and is, consequently, one of the most fruitful causes of railway accidents. It is positively forbidden, by most of the French railways and manufacturers, ever to throw a rail down, or allow it to drop from any height. To discharge it from the car, at least two rails are required to be placed as skids, upon which the rails are to slide to the ground. They are then to be lifted to the place to which they are to go. When rails are being piled up, at the works, these skids are a great convenience to the workmen, and they are always used; but, in discharging them from cars, they are not, as it is often inconvenient to place them, and whenever the men think that they are not watched, they will discharge the rails by throwing them, but when this is discovered, it is always punished.

It is generally in the winter that the largest number of rails are broken, and there has been a great deal of speculation, but very few experiments with regard to the effect of cold upon the wear of iron and steel rails. I had devised a method of making such tests, and was to have made a very large series of experiments upon this subject, but unfortunately, was prevented. I am inclined to think, however, from a preliminary examination of the subject, that the cause of fracture is not so much owing to the cold—though both iron and steel have a diminished power of resistance, when subjected to great cold—as to the fact that the road-bed is entirely frozen and ridged during many months at a time. The want of elasticity in the road-bed would tend to increase any flaws that might have been started, and the shock of the passing trains would have a much greater effect upon the rail during the winter than during the summer months, when part of the shock is diminished by the elasticity of the road-bed. The road-bed is also less capable of inspection in the winter, owing to the accumulation of ice and snow, and a crack or flaw commenced, is less likely to be seen, or a broken rail is more likely to be kept in its place, for a certain time, than in summer, and is therefore less likely to be removed before an accident occurs. I am sustained in this opinion by some of the best engineers in Europe.

It is greatly to be wished that some such tests as I had proposed

to make, should be carried out by some of our roads, in order that this point may be definitely settled, and that we may know exactly how far the strength of the rail is diminished by the cold of the winter. When this is known it is probable some remedy will be found for the greater number of accidents caused by broken rails in the winter months.

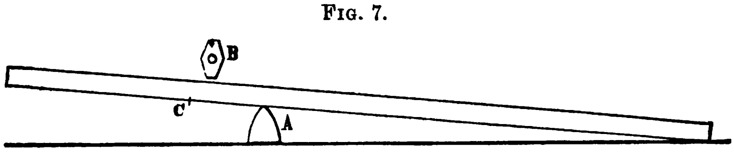
In closing this paper, I must express my warmest thanks to the Orleans and Lyons Railway Company, of France, whose engineers entered heartily into my plans of collecting statistics and specific information relating to the broken rails which were sent to me for further investigation. To the engineers of the Northern Railroad of France, who not only furnished me with a large amount of information, but allowed me to frequently use their shops without charge. I can only express to them and to the Institute my very great regret that the panic of 1873, which has so seriously affected the whole of this country, prevented the investigation from being more than fairly commenced in Europe, and did not allow of anything being done in this country.

Mr. JOHN FRITZ remarked that the fracture of steel rails was referable either to abnormal chemical composition or improper mechanical treatment. Often we have in the chemical composition alone a sufficient cause for breakage. It is known that where the amount of carbon is high, the amount of silicon and phosphorus must be low. He had, for instance, examined two foreign rails of the same make which broke in the track. One contained 0.16 per cent. carbon, 0.087 silicon, and 0.127 phosphorus; the other 0.58 carbon, 0.56 silicon, and 0.112 phosphorus. They were both forged out to small bars, and while the first could be bent double cold, the last broke at the first attempt to bend it. But more important, if possible, than the chemical composition is the mechanical treatment. All violent disturbance of the molecular arrangement of the particles of the steel when cold, as in straightening, punching, notching, etc., tends to make it brittle. Sandberg has shown that hard steel rails which were notched on the flange suffered a loss of strength of 50 to 97 per cent.—the former where the notch was semicircular, and the latter when the notch was square. At the Bethlehem Iron Works, a sample ingot is taken from each blow, forged out to a bar about $\frac{3}{4}$ by 1 inch, and bent until the ends meet. From this ingot samples are also taken for analysis. A rail from each heat is further sub-

jected to a drop test of 2000 pounds falling fifteen feet. When the rail is notched or punched, it will sometimes break with a drop of one foot. The question naturally arises, Why expend so much care on a rail that will stand the fifteen feet drop, and then deliberately reduce the strength 90 per cent. or more at each end? The advantage in favor of drilling over punching is very marked. Where a punched rail will break with a drop of one to two feet, a drilled rail will stand eight to ten. Not long since an engine on the Lehigh Valley Railroad ran off the track and struck a number of steel rails on the sides or flanges. All of these rails broke shortly after in the track. With regard to iron rails, it is simply a matter of good iron and of dollars and cents. There is no mystery here, and it is not worth discussion.

Mr. W. A. SWEET, of Syracuse, said: While I am neither a manufacturer of steel rails nor a user of them, my experience as a manipulator of rail-ends and old rails has given me great and varied experience in the breaking of rails, and has led me to conclusions perhaps different from any one present. Not having shears sufficiently strong to cut a steel rail, it has been a study with me to find a way to break old steel rails with the least physical labor. I find, by arranging the rail as shown in the accompanying sketch, where A represents the point of support, B the sledge, and C the position of

FIG. 7.



the nick in the flange, the rail is almost invariably broken at the first blow. There is a perceptible time, after striking the blow, before the suspended end drops off, appearing as if a wave of vibration passed to the end and back again to the point where the flange is cut, where it seems to stop suddenly, the wave of vibration appearing to me to be arrested and concentrated to that extent that the molecular constitution of the metal is destroyed. It may be, however, that the vibrations do not go to the end and return, but are arrested in the first instance at the point where the nick or dent is made. That it is a wave of vibration that causes breaking in steel rails I am fully convinced. I do not think that the cutting or punching of the holes for the fish-plate bolts would weaken the rail beyond what would be produced by the removal of so much metal, provided that the rails

had been rolled at the proper temperature when finished. But where the ends are allowed to get loose, my opinion is that they break at the remote end, after the passage of the last wheel of the train.

I think if a rail is actually tight in the fish-plate (and but few are), there will be no breakage without the cause is on the face of it, as by the running off of the cars, or some actual duty too great for their strength to bear.

It is well known that bells are supposed to be made the proper shape to throw off vibration, and to continue to do it for years without breaking. When one is not so proportioned it soon breaks, and must be replaced by a new one, and no credit accrues to the maker of the faulty one.

In the case of a rail, we have a bar equal in size from end to end, and it only wants a mark or dent with a hammer to arrest the waves a few times, and the result is a break. The now accepted fact, that punching the holes for the fish-plate bolts weakens the rail 75 per cent., shows, to a thinking mind, that there is something wrong, either in the molecular construction of the metal itself, or in its manipulation.

I claim, and have for years, that it is in the *manipulation;* that steel rails have not yet been rolled properly, or finished at a proper heat. They should be rolled and finished in chilled rolls, with finished passes, and at a heat that will just set the scale. Having rolled thousands of tons of rail-ends into small bars, and so treated them that they will bend double and stand pounding down flat, I feel prepared to say that, if rails were rolled as we roll tire steel, they would stand ten times the shock they now will, and that punching the holes would weaken them only in proportion to the amount of metal removed.

We are taking Bessemer steel and converting it into blister steel by the cementing process (imparting to it enough carbon, so that by analysis it shows 1 per cent.), rolling it into spring steel, and from it making hundreds of pairs of springs per day. The leaves of the same are 1¼ inches wide, with three holes, 5-16 inches in diameter, punched in each one, and when they are tested they do not break in the holes. There are many thousands of our tire for carriages, where the bolt-hole is more than ¼ the width of the tire, and a tire from this stock is scarcely ever broken. The tire is strained on the wheel in setting, as is well known, and receives many blows from contact with the pavements, fully equal to what rails are subjected to, and probably much more in proportion to the actual weight of its section.